Appendix A. Automated Detection and Classification of Marine Mammal Vocalizations and Anthropogenic Noise

This appendix describes the methods developed by JASCO Applied Sciences Ltd. for automated detection of bearded seal calls, beluga whistles, bowhead moans, bowhead songs, and walrus grunts within the data collected during the winter 2014−2015 and summer 2015 seasons of the Acoustic Monitoring Program in the northeastern Chukchi Sea. The algorithms, developed by JASCO, and their performance are described.

A.1. Test Datasets

The automated detectors/classifiers must be verified with a test dataset that represents the spatio-temporal variations of the marine mammal calls and background noise in the entire dataset. Since the acoustic environment in the eastern Chukchi Sea differs between winter and summer, a unique test dataset was used to test the detection/classification algorithms for each season. For the winter 2014–2015 Acoustic Monitoring Program data, marine mammal calls were fully manually-annotated in 81 samples adding up to 1.8 hours of recordings chosen from Stations CL5, PL10, PL50, PLN40, W10, W50, and WN40. For the summer 2015 Acoustic Monitoring Program data, marine mammal calls were fully manually-annotated in 67 samples adding up to 3.5 hours of recordings chosen from Stations CL5, CLN40, CLN90B, CLN120B, PL10, PL30, PLN20, PLN60, PLN80, W10, W30, W50, HSW1, HSW2, HSW3, B5, B15, and B30.

A.2. Detector/Classifier Performance

The performance of each automated detector/classifier is evaluated using test datasets from both the winter 2014–2015 and summer 2015 programs. The test datasets consist of all fully manually-annotated data samples for each program. For each detector/classifier and each season's dataset, the precision (P) and recall (R) of the detector/classifier on the entire test dataset are given. The SNR distribution of the test dataset over four SNR intervals and the R values calculated for each SNR interval are shown in Figure A-1.

A.2.1. Bowhead Winter Songs

The bowhead winter song detector/classifier was tested against the fully manually-annotated recordings from winter 2014–2015. The test dataset had 247 manually-annotated bowhead songs (Figure A-1, left). The performance of the bowhead song detector/classifier on the test dataset yielded P = 0.96 and R = 0.34. The highest R value was 0.51, obtained for calls with SNRs between 5 and 10 dB (Figure A-1, right).

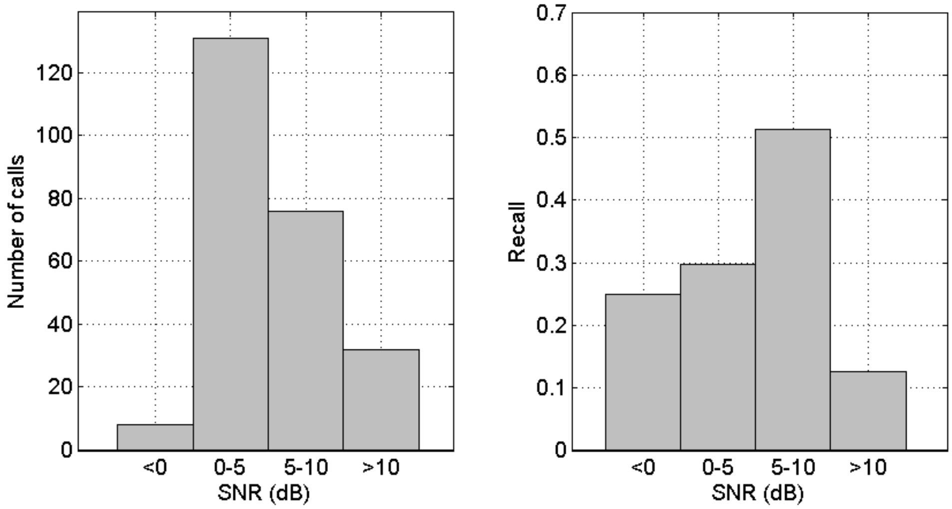

Figure A-1. Performance of the bowhead winter song detector/classifier on the winter 2014–2015 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

A.2.2. Bowhead Summer Moans

The bowhead summer moan detector/classifier was tested against fully-annotated recordings collected during the summer 2015 monitoring program. The test dataset had 250 manually-annotated bowhead moans (Figure A-2, left). The performance of the bowhead moan detector/classifier on the test dataset yielded $P = 0.92$ and $R = 0.53$. As expected, R increased with increasing SNR (Figure A-2, right).

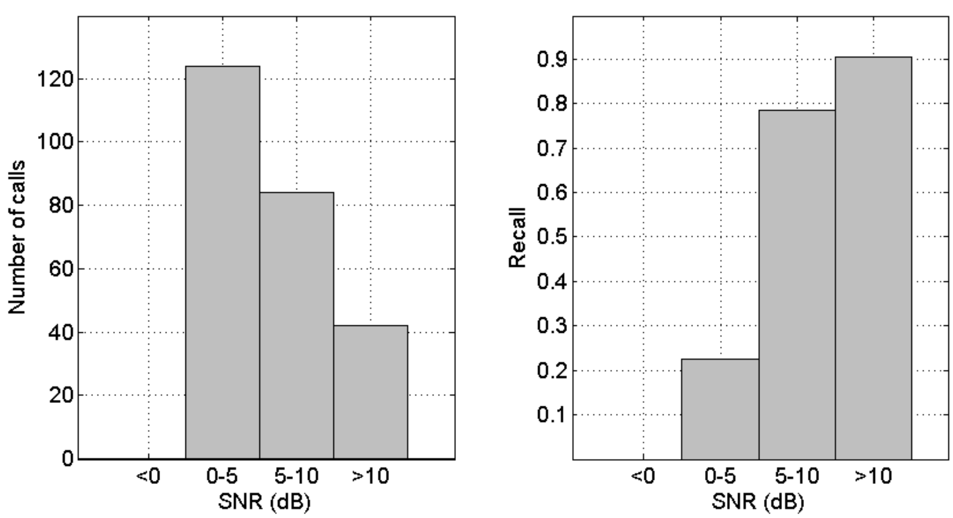

Figure A-2. Performance of the bowhead summer moan detector/classifier on the summer 2015 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

A.2.3. Beluga Whistles

The beluga whistle detector/classifier was used to analyze data from both the winter 2014–2015 and the summer 2015 monitoring programs. Performance of the detector/classifier was evaluated separately on each program given the very different characteristics of the background noise between the summer and the winter.

Winter 2014–2015 Program

The test winter dataset had 372 manually-annotated beluga whistles (Figure A-3, left). Most annotated whistles had a SNR between 0 and 5 dB. The beluga whistle detector/classifier had $P = 0.65$ and $R = 0.55$. The highest R was 0.61, obtained for whistles with SNR > 10 dB (Figure A-3, right).

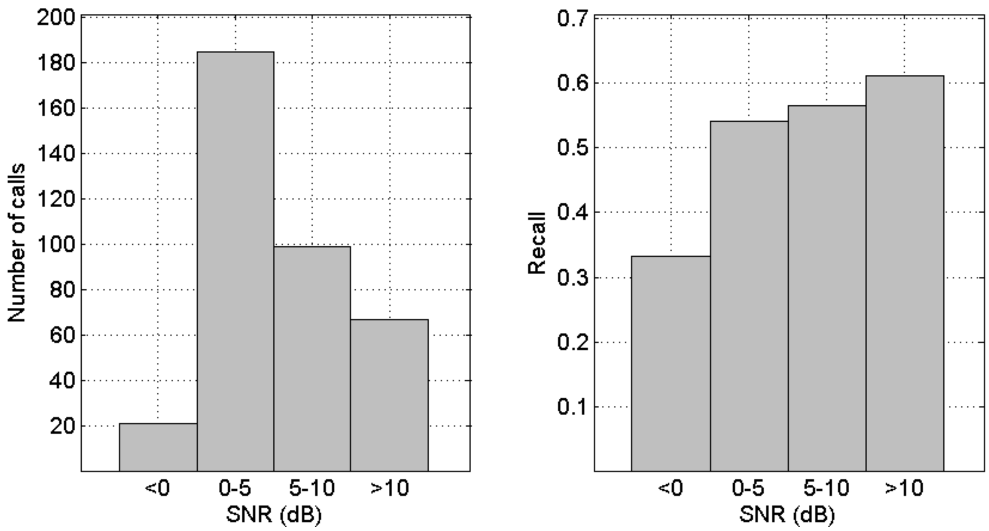

Figure A-3. Performance of the beluga whistle detector/classifier on the winter 2014–2015 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

Summer 2015 Program

The summer test dataset had 40 manually-annotated beluga whistles (Figure A-4 , left). Most annotated whistles had a SNR between 0 and 5 dB. The beluga whistle detector/classifier had $P = 0.92$ and $R = 0.61$. The highest R was 0.71, obtained for whistles with SNR between 5 and 10 dB (Figure A-4, right)

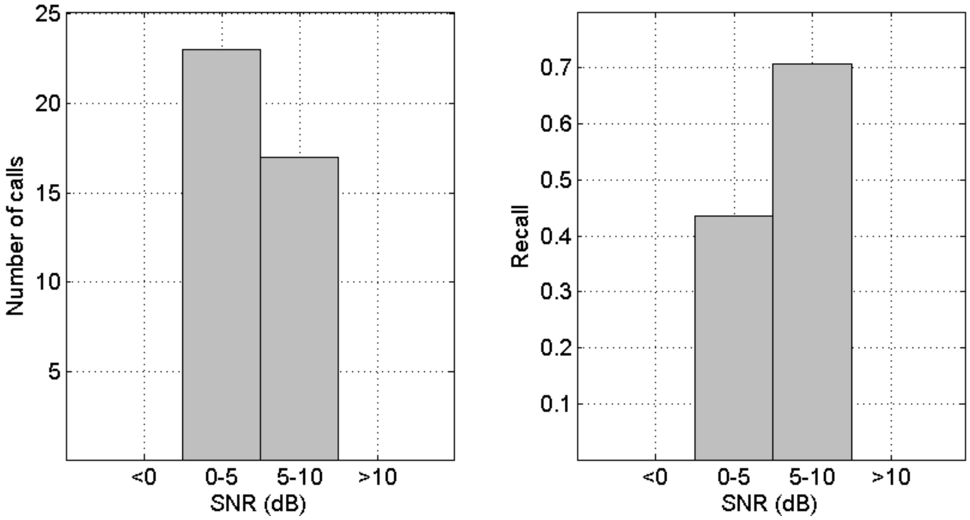

Figure A-4. Performance of the beluga whistle detector/classifier on the summer 2015 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

A.2.4. Walrus Grunts

Walrus grunts were recorded in both winter and summer. The performance of the walrus grunt detector/classifier was calculated for both the summer 2015 and the winter 2014–2015 datasets.

Winter 2014–2015 and Summer 2015 Program

The winter 2014–2015 and summer 2015 test dataset had 282 manually annotated walrus calls (Figure A-5, left). The walrus call detector/classifier had $P = 0.96$ and $R = 0.28$. The highest R was 0.6, obtained for grunts with SNR higher than 10 dB (Figure A-5, right).

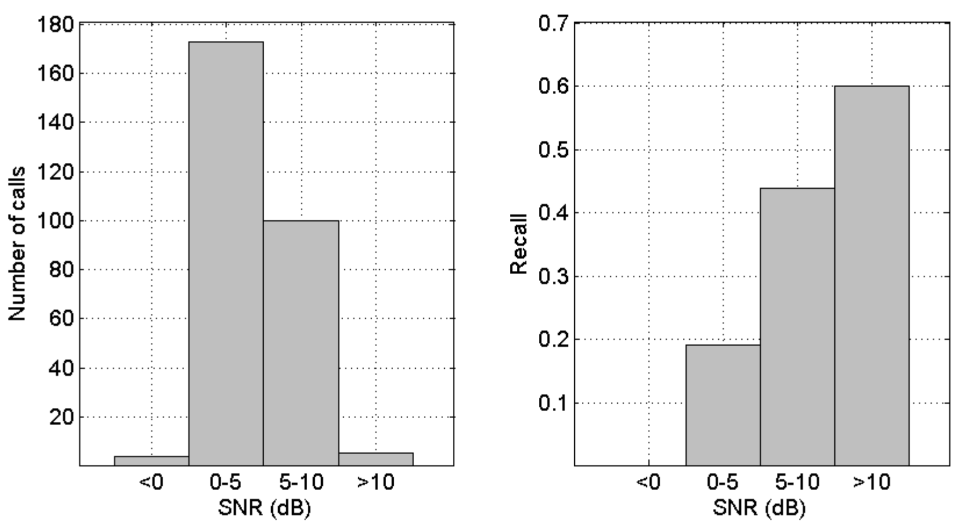

Figure A-5. Performance of the walrus grunt detector/classifier on the winter 2014–2015 and summer 2015 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the combined test datasets. (Right) Recall of the detector per call SNR interval.

A.2.5. Bearded Seal Calls

Bearded seal calls were recorded in both winter and summer. Therefore, the performance of the bearded seal calls detector/classifier was calculated independently for the summer 2015 and for the winter 2014–2015 datasets (i.e., one set of *P* and *R* values for each dataset).

Winter 2014–2015 Program

The winter 2014–2015 test dataset had 393 manually-annotated bearded seal calls (Figure A-6, left). The bearded seal call detector/classifier had *P* = 0.78 and *R* = 0.67 for this dataset. The highest *R* was 0.88 for calls with SNR between 5 dB and 10 dB (Figure A-6, right).

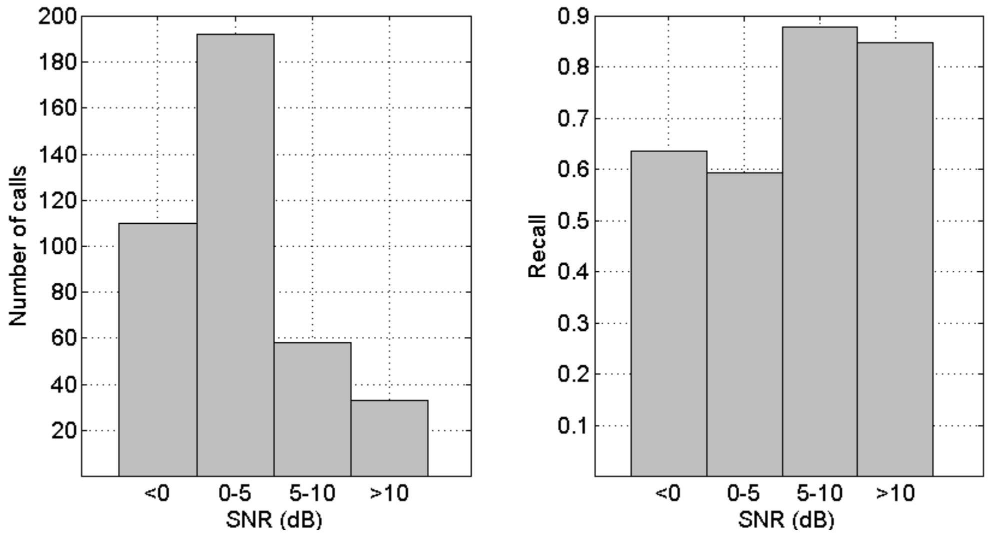

Figure A-6. Performance of the bearded seal detector/classifier on the winter 2014–2015 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

Summer 2015 Program

The summer 2015 test dataset had 115 manually-annotated bearded seal calls (Figure A-6, left). The bearded seal call detector/classifier had *P* = 0.79 and *R* = 0.43 for this dataset. The highest *R* was 1 and was obtained for calls with SNR > 5 dB (Figure A-6, right).

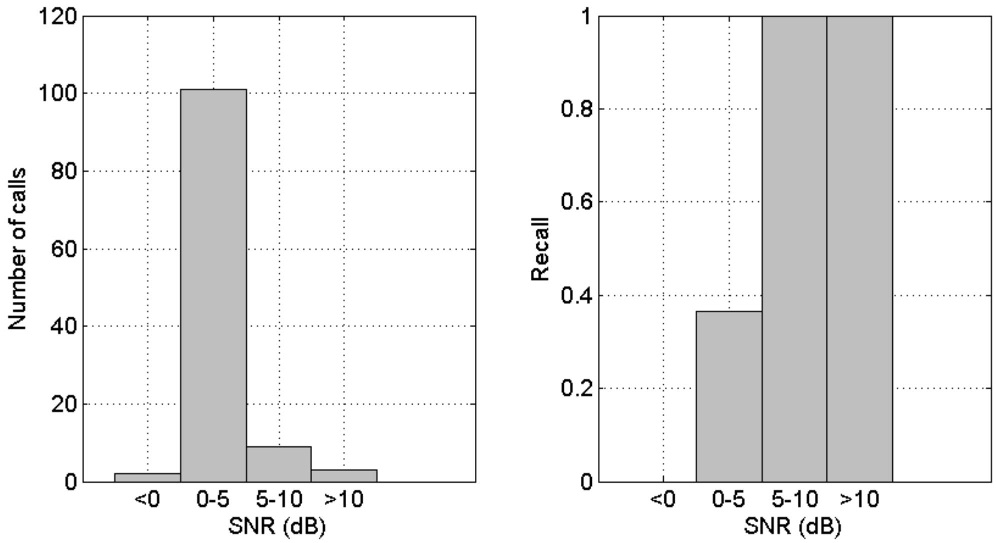

Figure A-7. Performance of the bearded seal detector/classifier on the summer 2015 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

A.2.6. Summary

Table A-1 summarizes the performance of each detector/classifier used in this study for each season.

Table A-1. Precision (*P*) and recall (*R*) for all SNRs of each detector/classifier.

Detector	*P*	*R*
Bowhead songs, winter	0.96	0.34
Bowhead moans, summer	0.92	0.53
Beluga whistles, winter	0.65	0.55
Beluga whistles, summer	0.92	0.61
Walrus grunts, winter and summer	0.96	0.28
Bearded seal, winter	0.78	0.67
Bearded seal, summer	0.79	0.43

A.3. Probability of Detection by Manual Analysis

To determine whether manually reviewing only 5% of the data provided an accurate estimate of the acoustic occurrence of marine mammal calls, analysts randomly selected, then fully-annotated more than 43 h of acoustic data containing a representative sample of the commonly detected species, specifically bowhead, beluga and gray whales, bearded and ringed seals, and walrus. Selected files were distributed across stations and over the whole recording period. For each file, an algorithm written for this purpose then chose a random start time and manually searched the next *n*% of the file (corresponding to the analysis sample) for manual annotations. *n* varied from 1 to 100% in increments of one. This random sample selection was iterated 2000 times per file for each sample size. A detection probability (DP) was obtained for each file and sample size by dividing the number of samples containing at least one annotation in the random sample by 2000. The comparison of detection probabilities across the sampling period provided an overview of seasonal and inter-specific variations.

A.3.1. Manual Analysis Detection Probability: Winter 2011–2012 and Summer 2012 Programs

Samples of data of 5% of each acoustic data file were manually analyzed to determine the presence of calls from each species in the winter and summer datasets. Calls were separated by call types (Table A-1). The goal of this analysis was to assess and validate the protocol of manual examination of a fraction of the datasets. The 5% manual analysis protocol is compared to estimated 1%, 2%, and 10% manual analysis protocols (Table A-2, Table A-3).

For bowhead whales, analysts annotated individual sounds, but did not distinguish or characterize songs (see for example Delarue et al. 2009). If analysts were unable to definitively identify a species in a sample, they would examine the source file of the sample for more easily identifiable calls within the same time window.

Table A-1. Call types by species annotated during manual analysis of the winter 2011–2012 and summer 2012 datasets. Abbreviations: AM = amplitude-modulated, FM = frequency-modulated, HF = high-frequency, LF = low-frequency.

Species	Call type	Description
Bowhead whale	Upsweep	Upsweeping FM tonal, usually below 600 Hz.
	Downsweep	Downsweeping FM tonal, usually below 600 Hz.
	Constant	Relatively flat FM tonal, usually below 600 Hz.
	Convex	Inflected FM tonal, increasing then decreasing in frequency. Usually below 600 Hz.
	Concave	Inflected FM tonal, decreasing then increasing in frequency. Usually below 600 Hz.
	Complex	FM moans with more than one inflection point and/or with harmonics. Any FM and AM calls extending above 600 Hz.
	Overlap	Overlapping calls produced concurrently by several individuals.
	Other	Bowhead calls outside the above categories.
Walrus	Knock	Broadband impulsive sounds typically occurring in long series.
	Bell	Tonal calls centered around 450 Hz and typically associated with knocks.
	Chimp	Two-part call reminiscent of chimpanzee vocalizations and often produced in long sequences. Sometimes repeated without interruption between consecutive units. Second part higher in frequency than first part.
	Grunt	Grunting sound. Often produced in pairs or triads repeated in long sequences.
	Bark	Often produced in pairs or triads repeated in long sequences. Similar to grunts, but higher in frequency (400 Hz).
	Snort	Snorting/burping sound typically increasing in frequency. Typically not produced in sequence.
	Tone	LF tonal calls, typically flat or downsweeping. Usually around 100–200 Hz. Similar to bowhead moans but shorter (< 0.5 s).
	Low-frequency downsweep	A short call (< 0.5 s) with features intermediate between a grunt and tone; fast downward sweep rate; less than 100 Hz and emphasis on LF (< 50 Hz)

Species	Call type	Description
	Overlap	Overlapping calls produced by several animals concurrently.
	Other	Walrus calls outside the above categories.
Beluga whale	Low whistle	FM calls without harmonics below 2500 Hz.
	High whistle	FM calls without harmonics above 2500 Hz.
	Buzz	Broadband buzzing sounds.
	Chirp	Very short, HF sound. Reminiscent of small bird chirps.
	Click	Broadband clicks, presumably echolocation related.
	Overlap	Overlapping calls produced by several animals concurrently.
	Other	Beluga calls outside the above categories.
Bearded seal	Long trill	Downsweeping trills longer than 6 s.
	Short trill	Downsweeping trills shorter than 6 s.
	Upsweeping trill	All upsweeping trills.
	Constant trill	Flat trills.
	Complex trill	Trills containing both up- and downsweeping segments.
	Overlap	Overlapping calls produced by several animals concurrently.
	Other	Bearded seal calls outside the above categories.

Species	Call type	Description
Fin whale	20 Hz pulse	Pulse downsweeping from 25 to 18 Hz, about 1 s long.
	Broadband downsweep	Same bottom frequency as 20 Hz pulse, but top frequency can extend up to 50 Hz or above.
	Other	Calls that do not match the above categories.
Gray whale	Knock	Knocking sounds. No frequency modulation.
	Click	Series of impulsive sounds similar to knocks but varying in pitch throughout the series.
	Grunt-like knock	Superposition of knocks and grunts.
	Moan/growl	Moans with harmonic. Very LF (fundamental near 100 Hz) with growly texture. Sometimes mixed with grunt-like knocks.
	Other	Calls outside the above categories.
Humpback whale	Grunt/snort, wop	AM calls often ascending in frequency at the end (e.g., Thompson et al. 1986).
	Other	Calls outside the above categories (e.g., moans, cries, etc.).
Killer whale	Pulsed call	Characterized by harmonic structure. Fundamental frequency usually around 800–1000 Hz. Expect repetitions of stereotyped calls within files.
	Whistle	FM calls usually without harmonics.
	Other	Calls outside the above categories.
Minke whale	Boing	Pulsed call with fundamental frequencies and harmonics around 1200–1500 Hz, 1–2 s long.
Ribbon seal	Medium downsweep	FM calls, sometimes with harmonic, downsweeping from 2–5 kHz to 100 Hz, usually < 2 s. Metallic texture and sonority.
	Other	Primarily contains the puffing sounds described by Watkins and Ray (1977). Includes other uncategorized calls.
Ringed seal	Bark	Short barking/grunting sounds below 1 kHz and produced in series; often alternating with yelps.
	Yelp	Short yelping sounds between 600–1000 Hz; can occur alone or in mixed sequences with barks.
	Other	Ringed seal calls outside the above categories.
Unknown	Undescribed	Any biological sound that cannot be classified as one of the above species; includes isolated calls that cannot be assigned to a species based on context. Most presumed ice seal calls were likely logged here.
	Grunt	Any grunt-like calls not likely produced by walrus.

The estimated DP for selected files that contain bowhead, beluga and gray whale, ringed and bearded seal, and walrus (Table A-2, Table A-3) calls indicate that the performance of the manual analysis protocol[1] varies with species and season.

Bowhead calls had a mean DP of 0.82 during the winter deployment (range: 0.33 to 1). DPs increased in late October, were highest in November, December, April, and May when bowheads

[1] i.e., The probability that a randomly selected 2 min/90 s [winter/summer] sample will contain calls of a given species if calls are present within its 40 min/30 min [winter/summer] source file.

produce long, elaborate songs (Delarue et al. 2009) as they migrate through the Chukchi Sea, and then decreased in late spring. The mean DP in summer 2012 was 0.55, which indicated lower calling rates in summer months. The high DP detected in the file recorded at the end of the summer Acoustic Monitoring Program, on 10 Oct, corresponded to the annual increase in vocal activity during fall associated with the onset of singing (Table A-3).

Bearded seal calls had a mean DP of 0.62 (range 0.09 to 1) during the winter deployment. DP was close or equal to 1 from November to early July, with one exception at CL50 in February. The mean DP (0.4) during the summer 2012 deployment persisted into fall, although some peaks in calling activity are possible, as indicated on 11 Oct at CL5 (Table A-2, Table A-3).

Beluga whales' DP was variable (mean: 0.56; range: 0.14 to 1) during the winter deployment. The highest DPs were recorded during the spring migration. The three summer 2012 files analyzed each had DP close or equal to 1 (Table A-2, Table A-3).

Ringed seals' DP was relatively constant throughout the year and consistently low, averaging 0.14 (Table A-2). Although not included in this analysis, summer data follow the same pattern (Delarue et al. 2011). This suggests the current analysis protocol underestimates the presence of ringed seal calls in the data (Table A-2, Table A-3).

Walrus calls typically have a high DP due to high calling rates, with a few exceptions. The mean DP was 0.71 and 0.87 in the winter and summer data, respectively (Table A-2, Table A-3).

Gray whale DP averaged 0.42 in the summer data (range: 0.13–1). A strong variability in DP, and therefore calling rate, was observed (Table A-3).

Table A-2. Manual analysis detection probabilities (DPs) of bowheads, belugas, ringed seals, bearded seals, and walrus for files recorded at several stations during the winter 2011–2012 program based on a manual review of 5% of the data. Results for each species are ordered chronologically. 1%, 2%, and 10% manual analysis protocols are estimates and are included here for comparison.

Species	Station	Date	DP (5%)	DP (1%)	DP (2%)	DP (10%)
Bearded seal	WN60	15 Sep 2011	0.21	0.06	0.10	0.34
	PLN40	17 Oct 2011	0.12	0.04	0.05	0.24
	WN20	16 Nov 2011	0.09	0.02	0.05	0.14
	PLN100	15 Dec 2011	0.94	0.61	0.74	1.00
	PL50	15 Jan 2012	1.00	1.00	1.00	1.00
	CL50	17 Feb 2012	0.24	0.12	0.16	0.27
	B5	19 Mar 2012	0.99	0.76	0.92	1.00
	W35	17 Apr 2012	1.00	1.00	1.00	1.00
	PLN100	3 Jul 2012	1.00	1.00	1.00	1.00
Beluga whale	WN60	7 Oct 2011	0.59	0.22	0.37	0.87
	W35	19 Oct 2011	0.30	0.06	0.13	0.40
	PLN80	7 Nov 2011	0.51	0.16	0.27	0.73
	CL50	23 Nov 2011	0.49	0.17	0.28	0.67
	B5	8 Dec 2011	0.14	0.03	0.06	0.24
	B5	15 Apr 2012	0.41	0.11	0.18	0.65
	PLN40	1 May 2012	0.24	0.07	0.12	0.37
	PL50	16 May 2012	1.00	0.94	0.99	1.00
	B5	1 Jun 2012	1.00	0.86	0.98	1.00

Species	Station	Date	DP (5%)	DP (1%)	DP (2%)	DP (10%)
	B5	3 Jul 2012	0.49	0.20	0.31	0.65
	B5	30 Jul 2012	0.98	0.58	0.76	1.00
Bowhead whale	WN80	27 Aug 2011	0.47	0.18	0.27	0.58
	PLN100	9 Oct 2011	0.67	0.20	0.35	0.81
	PLN40	25 Oct 2011	0.92	0.58	0.74	1.00
	W50	4 Nov 2011	1.00	1.00	1.00	1.00
	PL50	17 Nov 2011	1.00	1.00	1.00	1.00
	CL50	15 Dec 2011	1.00	1.00	1.00	1.00
	B5	15 Apr 2012	1.00	0.84	0.95	1.00
	W35	30 Apr 2012	0.81	0.40	0.59	0.93
	PL50	17 May 2012	0.90	0.36	0.61	1.00
	B5	23 May 2012	0.98	0.77	0.90	1.00
	PBN40	10 Jun 2012	0.33	0.10	0.18	0.50
	B5	22 Jul 2012	0.75	0.24	0.40	0.96
Ringed seal	WN60	8 Oct 2011	0.25	0.07	0.12	0.51
	W35	22 Nov 2011	0.40	0.12	0.18	0.55
	PBN20	15 Dec 2011	0.05	0.01	0.03	0.06
	W50	15 Jan 2012	0.15	0.03	0.07	0.31
	PBN40	18 Feb 2012	0.01	0.01	0.01	0.01
	WN80	18 Mar 2012	0.09	0.01	0.03	0.16
	PL50	22 Apr 2012	0.11	0.04	0.08	0.17
	PLN120	13 May 2012	0.08	0.02	0.03	0.09
Walrus	WN80	28 Aug 2011	0.90	0.51	0.68	1.00
	PN120	16 Sep 2011	0.36	0.15	0.24	0.49
	WN20	15 Oct 2011	0.98	0.72	0.84	1.00
	WN40	1 Nov 2011	0.15	0.05	0.09	0.27
	PLN80	3 Dec 2011	0.98	0.73	0.85	1.00
	PLN100	24 Jun 2012	1.00	0.77	0.90	1.00
	B5	26 Jul 2012	0.59	0.29	0.39	0.77

Table A-3. Manual analysis detection probabilities (DPs) of bowheads, belugas, ringed seals, bearded seals, and walrus for files recorded at several stations during the summer 2012 program based on a manual review of 5% of the data. Results for each species are ordered chronologically. 1%, 2%, and 10% manual analysis protocols are estimates and are included here for comparison.

Species	Station	Date	DP (5%)	DP (1%)	DP (2%)	DP (10%)
Bearded seal	CLN90	13 Aug 2012	0.56	0.23	0.34	0.74
	W35	25 Aug 2012	0.02	0.01	0.02	0.02
	B5	10 Sep 2012	0.03	0.03	0.04	0.03
	PLN80	29 Sep 2012	0.40	0.11	0.21	0.61
	CL5	11 Oct 2012	1.00	0.34	0.66	1.00
Beluga whale	B5	15 Aug 2012	0.97	0.38	0.69	1.00
	B50	30 Sep 2012	1.00	1.00	1.00	1.00
	WN40	7 Oct 2012	0.96	0.37	0.63	1.00
Bowhead whale	CLN120	13 Aug 2012	0.45	0.13	0.22	0.67
	W20	9 Sep 2012	0.58	0.15	0.26	0.87
	B30	20 Sep 2012	0.54	0.16	0.30	0.80
	PLN60	30 Sep 2012	0.19	0.05	0.08	0.26
	BG07	10 Oct 2012	0.98	0.44	0.69	1.00
Gray whale	PL50	13 Aug 2012	1.00	1.00	1.00	1.00
	PLN40	26 Aug 2012	0.25	0.05	0.11	0.45
	W50	7 Sep 2012	0.13	0.03	0.05	0.23
	W20	20 Sep 2012	0.57	0.17	0.28	0.77
	PL35	9 Oct 2012	0.15	0.03	0.06	0.28
Walrus	CLN120	10 Aug 2012	1.00	1.00	1.00	1.00
	PLN40	25 Aug 2012	0.36	0.10	0.19	0.61
	PL50	10 Sep 2012	1.00	1.00	1.00	1.00
	WN40	25 Sep 2012	1.00	1.00	1.00	1.00
	BG08	10 Oct 2012	0.98	0.34	0.64	1.00

Figure A-8 suggests that a substantial increase in the length of the analysis sample would be required to reach 50% DP for ringed seals. Bowhead, bearded seal, and walrus DPs with a 5% analysis sample are all above 60% and would not significantly benefit by increasing the sample size. Simply doubling the sample size would raise the DP near or above 70% for all species except ringed seals.

For the summer data, a doubling of the sample size would raise the detection probability of gray whales and bearded seals near 50%, and that of bowheads to just above 70% (Figure A-9).

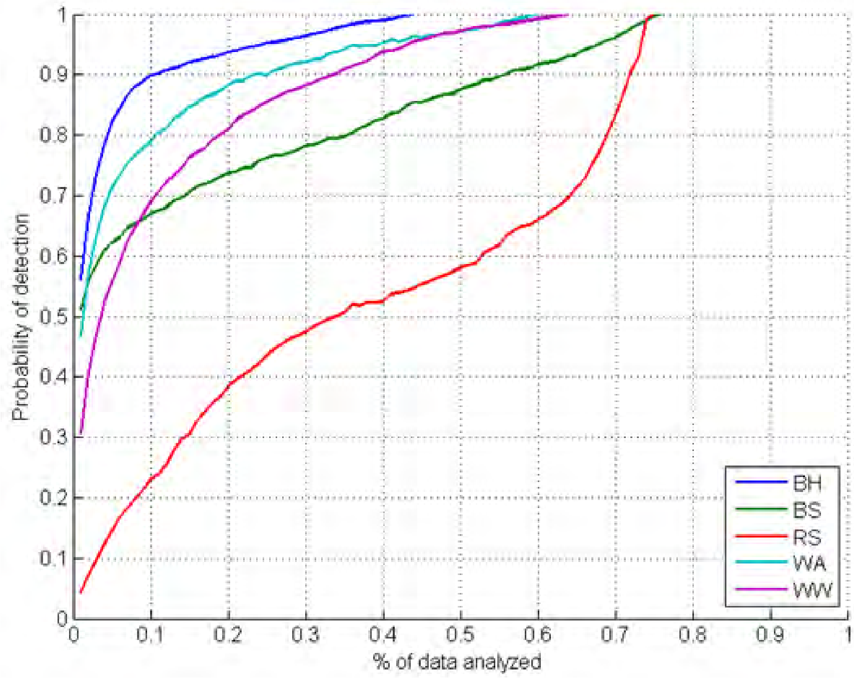

Figure A-8. Detection probability for bowhead and beluga whales, ringed and bearded seals, and walrus as a function of the percent data manually analyzed for a sample of files recorded during the winter 2011-2012 in the northeastern Chukchi Sea.

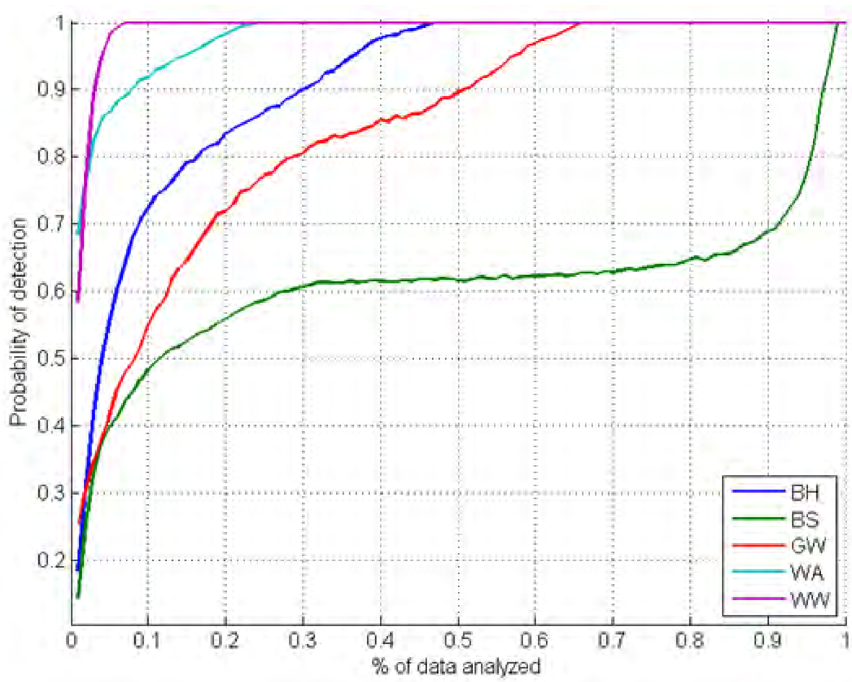

Figure A-9. Detection probability for bowhead, gray, and beluga whales, bearded seals, and walrus as a function of the percent data manually analyzed for a sample of files recorded during the summer 2012 in the northeastern Chukchi Sea.

A.4. Vessel Noise Detection

Ships' propulsion system and other rotating machinery produce narrowband tones (tonals) which can be easily detected. The tonals detector is based on overlapped Fast Fourier Transforms (FFT). The number of seconds of data input to the FFT determines its spectral resolution. Arveson and Vendittis (2000) used both 0.5 and 0.125 Hz resolutions. For this study, spectral analysis was performed at 0.125 Hz resolution by using 8 s of real data with a 2 s advance. This frequency resolution separates the tones from each other for easy detection, and the 2 s advance provides suitable temporal resolution. Higher frequency resolutions can reduce detectability of shipping tones, which are often unstable within 1/16 Hz for long periods. A 120 s long spectrogram is created with 0.125 Hz frequency resolution and 2 s time resolution (524 288-point FFTs, 512 000 real data points, 128 000-point advance, Hamming window). A split-window normalizer (Struzinski and Lowe 1984) distinguishes the tonal peaks from the background (2 Hz window, 0.75 Hz notch, and detection threshold of 4 times the median). The peaks are joined with a 3 × 3 kernel to create contours. Associations in frequency are made if contours occur at the same time. The event time and number of tones for any event at least 20 s long and 40 Hz in bandwidth are recorded for further analysis.

A.5. Seismic Survey Detection

There are measures taken to minimize the occurrence of false alarms, especially from biological sources. For example, sequences with a duration standard deviation greater than 0.2+(number of pulses)/30 s are rejected.

The 100% SEL is computed by adding 0.46 dB to the SEL computed over the 90% rms SPL window, and the pulse time, duration, 90% rms SPL, and SEL are stored for later use. The detected peaks are removed from the event time series and the process is repeated to look for weaker sequences or changes in sequence timing.

This detector requires post-processing to handle some situations. If the pulse period is unstable by more than 0.25 s, the detector cannot "lock-on". Also, if fewer than six pulses occur at the beginning or end of a WAV file at a particular repetition rate, they are missed. Post-processing is applied to address these issues and smooth the results. If at least 8 out of 20 min have seismic detections, then the other 12 min might have missed detecting some seismic pulses. There are three tests to detect possible seismic pulses: (1) The standard deviation in the number of shots per minute is less than 2; (2) The rms SPL during that period is stable within 3 dB and is greater than 125 dB; (3) The 1 min seismic SEL for the minutes with seismic pulses is within 6 dB of the total 1 min SEL. Seismic survey noise is declared missing for the minutes that meet these criteria. The missing minutes are filled in using the 1 min rms SPL and SEL from the ambient computations minus the mean difference between the 1 min seismic SEL and the 1 min ambient SEL.

A.6. Notes on Spectrogram Processing

This report contains many grayscale and color spectrograms representing the spectral evolution with time of sounds recorded during the acoustics programs in the northeastern Chukchi Sea.

The horizontal axis of these figures is time and the vertical axis is frequency, so that the plot provides a visualization of time-varying frequency content of the acoustic data. The spectrograms were processed to exploit the spectral contrast of the signal of interest visually for purposes of the discussion, and therefore the displayed traces do not provide a direct measure of the received SPL.

The caption of each spectrogram describes how the spectrogram was created, including:

FFT Size

Number of points (pts) in each fast Fourier transform (FFT). The acoustic data have a sample rate of 16,384 Hz (samples per second), so a 4096 pt FFT has 4 Hz resolution, and a 16,384 pt FFT has 1 Hz resolution.

Frame Size

Number of actual data points in each FFT. Often less than the FFT size. The actual data points are zero-padded out to the FFT size, which allows display of the spectral content at a high frequency-resolution while maintaining sufficient time resolution for short-duration events. Since many signals of interest are short duration transients, fewer real data points were used in the FFT window to more clearly show the rapid time evolution.

Time step

Number of data points overlapped from one FFT to the next. Generally half the number of real samples, but could be more for finer time resolution.

Window

Type of windowing function applied to the data before FFT to reduce spectral leakage.

Normalization

Most spectrograms in this report are normalized for improved display. Because normalization optimizes contrast in each region of the plot so that both weak and intense signals are similarly visible, the displayed grayscales or colors no longer represent the sound spectral pressure level, as they would without normalization.

Normalization steps we applied:

Step 1: For each frequency bin, compute the average level over the entire file.

Step 2: For each time step, compute a moving average of the results from Step 1, with a frequency bandwidth of 200 Hz.

Normalize each time-frequency bin by the average of Step 1, and the value from Step 2 that is 300 Hz above the current frequency.

Appendix B. Ambient Noise Results

B.1. Analysis Methods

Ambient noise levels at all winter and summer recording stations were examined to document baseline underwater sound conditions in the Chukchi Sea.

Ambient noise levels at each recording station are presented as:

- Statistical distribution of sound pressure levels in each 1/3-octave band. The boxes of the statistical distributions indicate the first (25%), second (50%), and third (75%) quartiles. The whiskers indicate the maximum and minimum range of the data. The red line indicates the root-mean-square (rms) in each 1/3-octave.
- Spectral level percentiles: Histograms of each frequency bin per 1 min of data. The 5th, 25th, 50th, 75th, and 95th percentiles are plotted. The 95th percentile curve is the frequency-dependent level exceeded by 5% of the 1 min averages. Equivalently, 95% of the 1 min spectral levels are below the 95th percentile curve.
- Broadband and approximate-decade-band sound pressure levels (SPLs) over time for these frequency bands: 10 Hz to 8 kHz, 10–100 Hz, 100 Hz to 1 kHz, and 1–8 kHz.
- Spectrograms: Ambient noise at each station was analyzed by Hamming-windowed fast Fourier transforms (FFTs), with 1 Hz resolution and 50% window overlap. The 120 FFTs performed with these settings are averaged to yield 1 min average spectra.
- Daily sound exposure levels (SEL (24 h)): computed for the total received sound energy, the detected seismic survey energy, and the detected shipping energy. The SEL (24 h) is the linear sum of the 1 min sound exposure levels (SELs). For shipping, the 1 min SELs (24 h) are the linear 1 min squared rms levels multiplied by the duration, 60 s. For seismic survey pulses, the 1 min SEL is the linear sum of the per-pulse SELs.

The 50th percentile (median of 1 min spectral averages) can be compared to the well-known Wenz ambient noise curves, which show ranges of variability of ambient spectral levels as a function of frequency of measurements off the US Pacific coast over a range of weather, vessel traffic, and geologic conditions. The Wenz curve levels are generalized and are used for approximate comparisons only.

The 1 min averaged, 1 Hz spectral density levels are summed over the 1/3-octave and decade bands to obtain 1 min averaged broadband levels (dB re 1 μPa). These values are available on request. Table B-1 lists the 1/3-octave band frequencies, Table B-2 the decade-band frequencies. Weather and ice coverage conditions throughout the deployment periods are also provided.

Table B-1. Third-octave band frequencies (Hz).

Band	Lower frequency	Nominal center frequency	Upper frequency
1	8.9	10	11.2
2	11.6	13	14.6
3	14.3	16	17.9
4	17.8	20	22.4
5	22.3	25	28.0
6	28.5	32	35.9
7	35.6	40	44.9
8	45.0	51	57.2
9	57.0	64	71.8
10	72.0	81	90.9
11	90.9	102	114.4
12	114.1	128	143.7
13	143.4	161	180.7
14	180.8	203	227.9
15	228.0	256	287.4
16	287.7	323	362.6
17	362.7	406	455.7
18	456.1	512	574.7
19	574.6	645	723.9
20	724.2	813	912.6
21	912.3	1024	1149
22	1,150	1,290	1,447
23	1,448	1,625	1,824
24	1,824	2,048	2,297
25	2,298	2,580	2,896
26	2,896	3,251	3,649
27	3,649	4,096	4,597
28	4,598	5,161	5,793
29	5,793	6,502	7,298
30	7,298	8,192	9,195
31	9,195	10,321	11,585
32	11,585	13,004	14,597

Table B-2. Decade-band frequencies (Hz).

Decade band	Lower frequency	Nominal center frequency	Upper frequency
2	10	50	100
3	100	500	1,000
4	1,000	5,000	10,000

B.2. Winter 2014–2015 Program

B.2.1. One-Third-Octave Band Sound Pressure and Power Spectral Density Levels

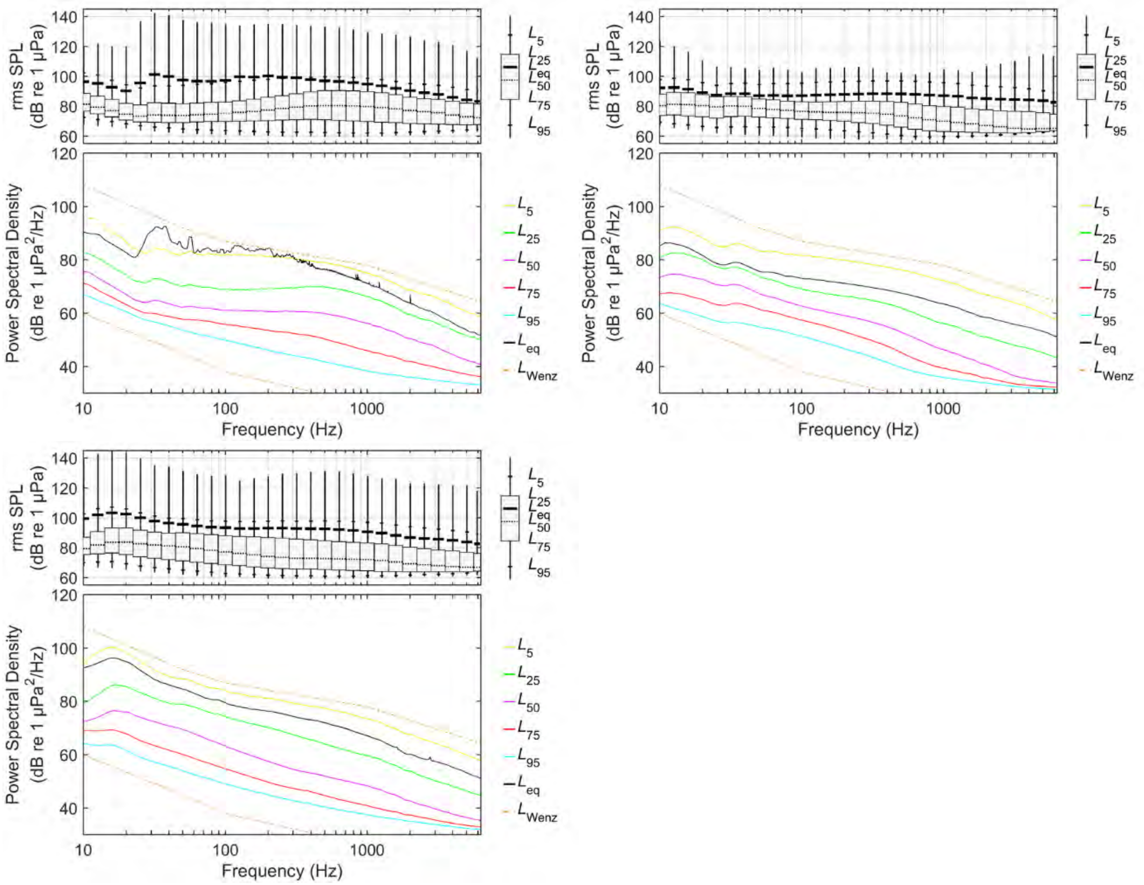

Figure B-1. 1/3-octave band sound pressure levels, mean and percentile 1-min power spectral density levels for winter 2014–2015 stations. (Top left) W10, (top right) W50, and (bottom) WN40.

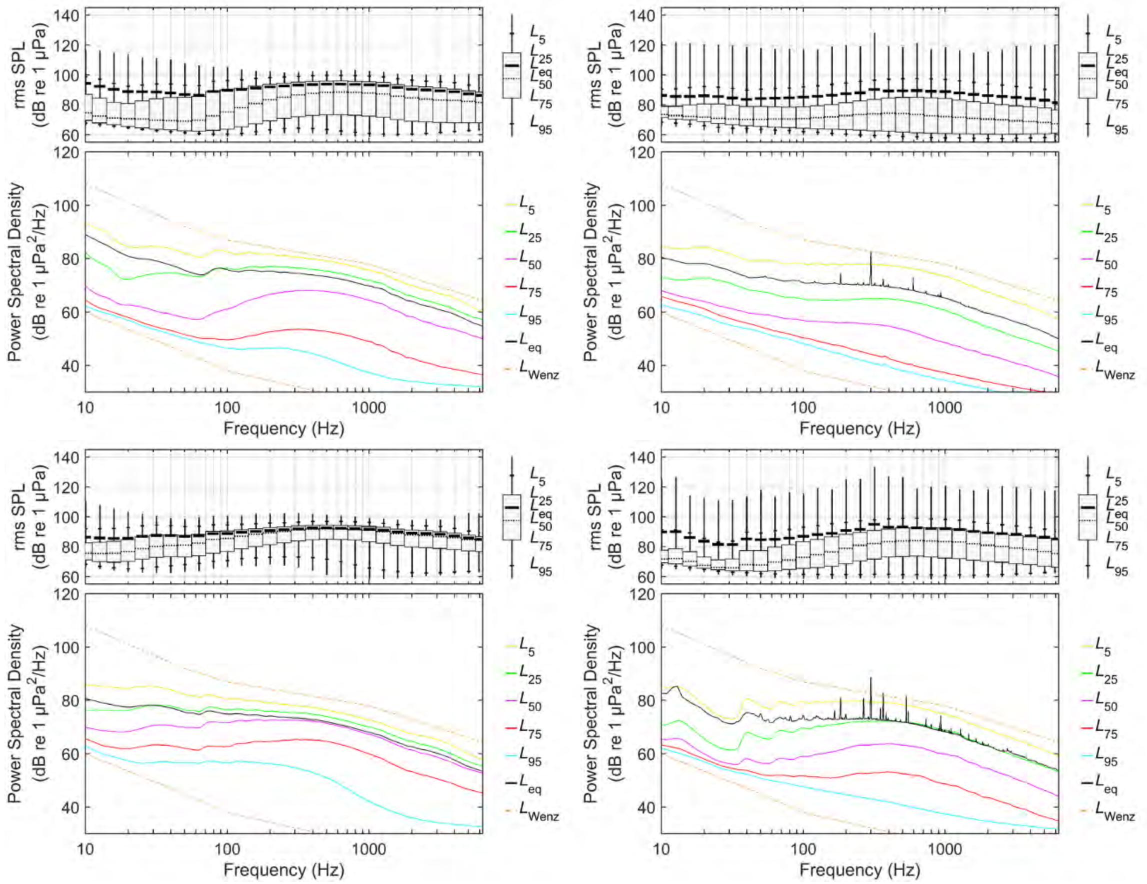

Figure B-2. 1/3-octave band sound pressure levels, mean, and percentile 1-min power spectral density levels for winter 2014–2015 stations. (Top left) PL10, (top right) PL50, (bottom left) PLN40, and (bottom right) CL5.

B.2.2. Broadband and Decade-Band Sound Pressure Levels and Spectrograms

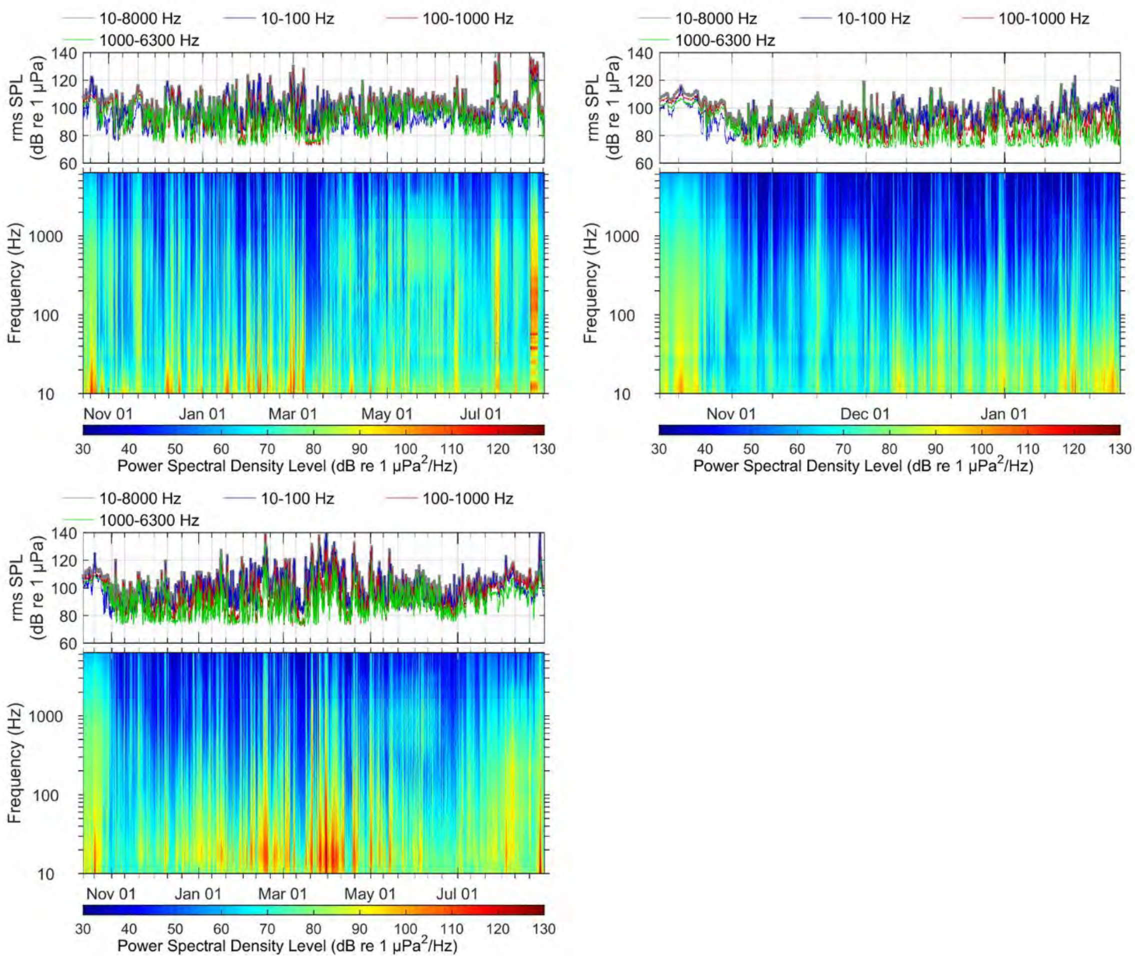

Figure B-3. Broadband and in-band sound pressure levels (SPLs) and spectrograms for winter 2014–2015 stations. (Top left) W10, (top right) W50, and (bottom) WN40.

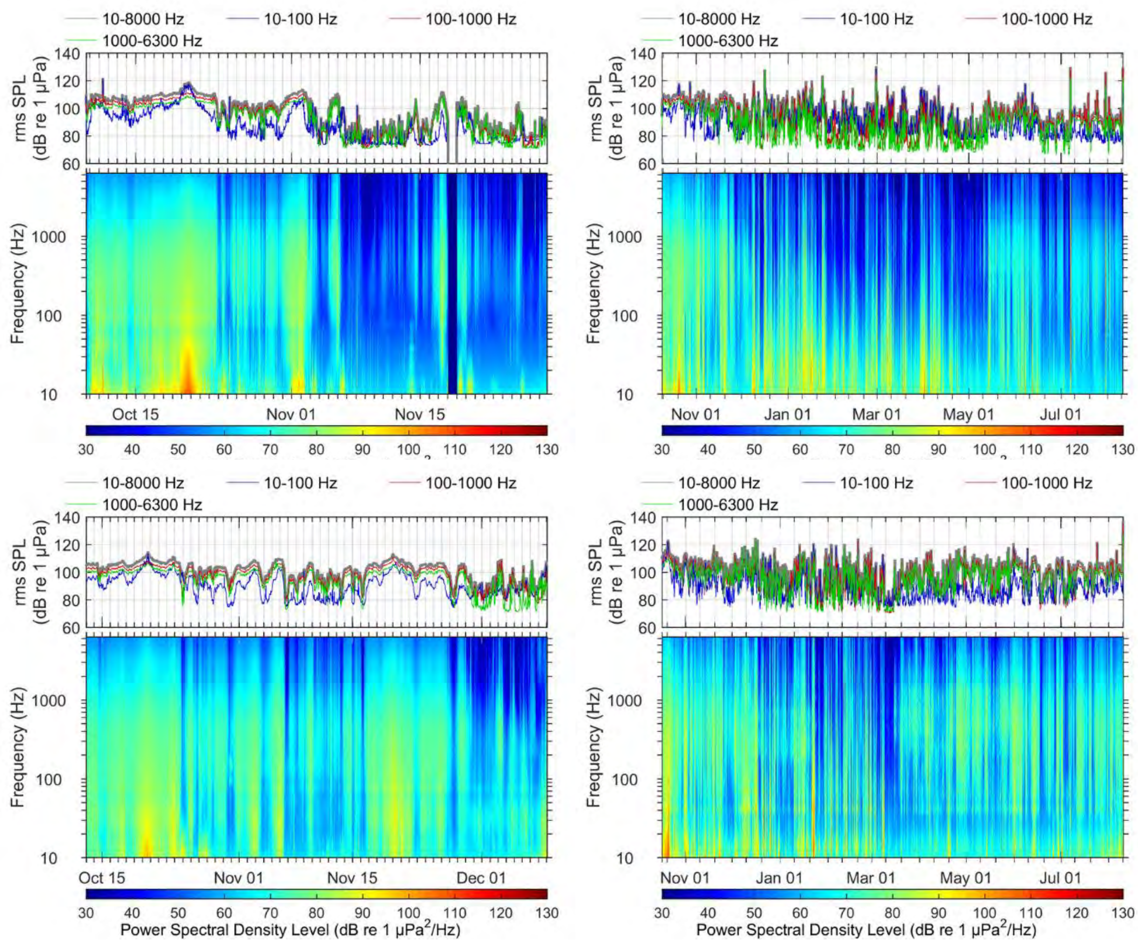

Figure B-4. Broadband and in-band sound pressure levels (SPLs) and spectrograms for winter 2014–2015 stations. (Top left) PL10, (top right) PL50, (bottom left) PLN40, and (bottom right) CL5.

B.2.3. Daily Sound Exposure Level

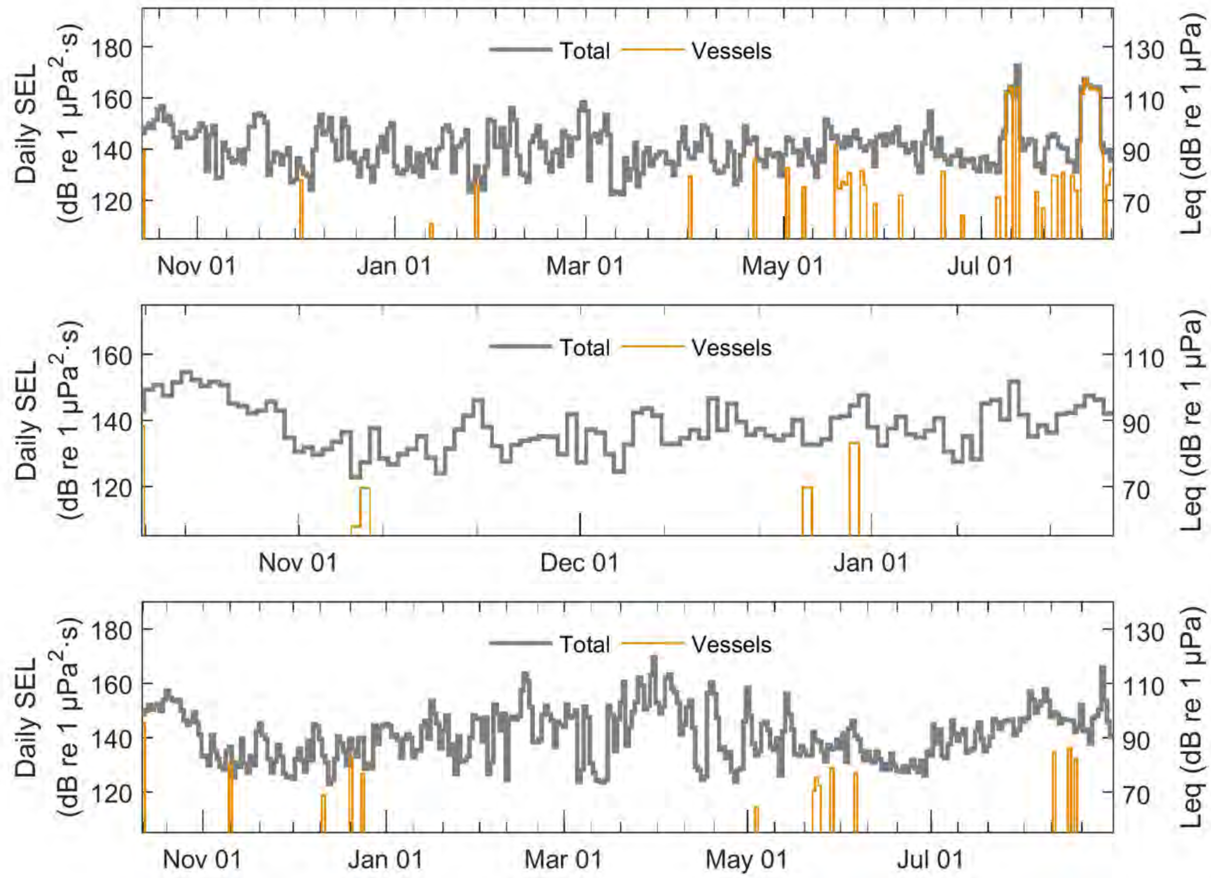

Figure B-5. Daily sound exposure level (SEL 24 h) distributions for winter 2014-2015. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: W10, W50, and WN40.

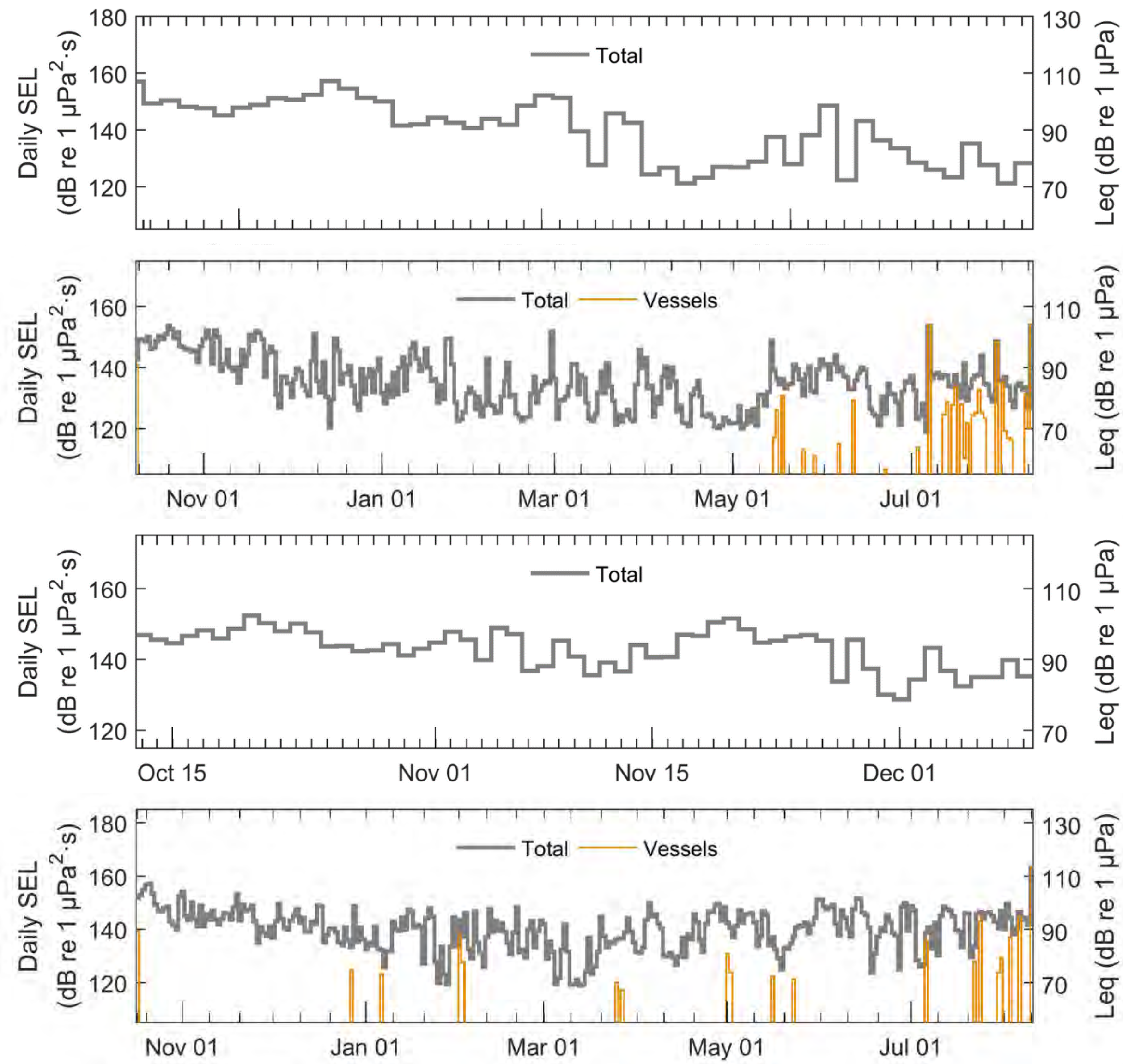

Figure B-6. Daily sound exposure level (SEL 24 h) distributions for winter 2014-2015. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: PL10, PL50, PLN40, and CL5.

B.3. Summer 2015 Program

B.3.1. One-Third-Octave Band Sound Pressure and Power Spectral Density Levels

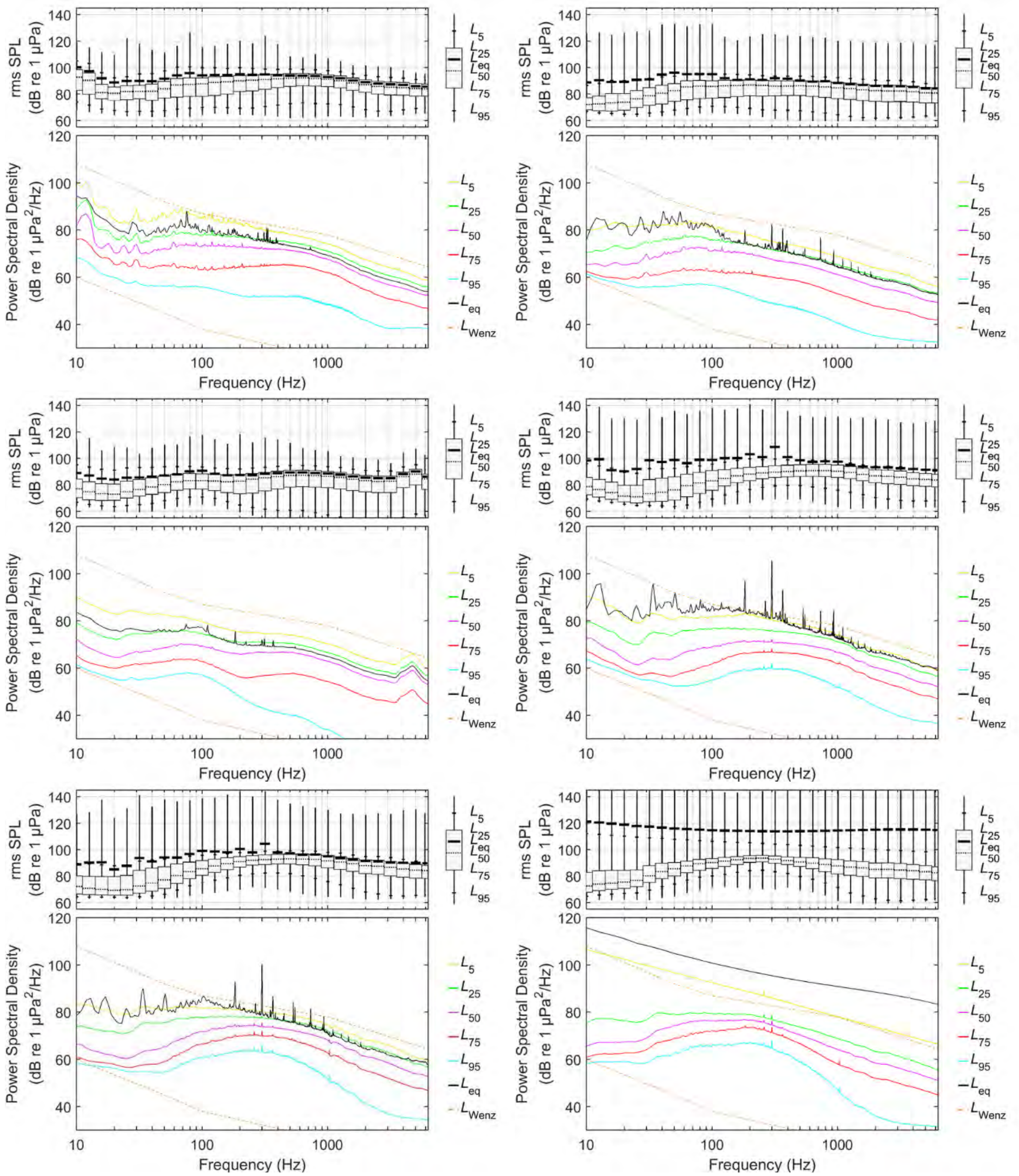

Figure B-7. 1/3-octave band sound pressure levels and percentile 1-min power spectral density levels for summer 2015 stations. (Top left) B5, (top right) B15, (middle left) B30, (middle right) W10, (bottom left) W30, and (bottom right) W50.

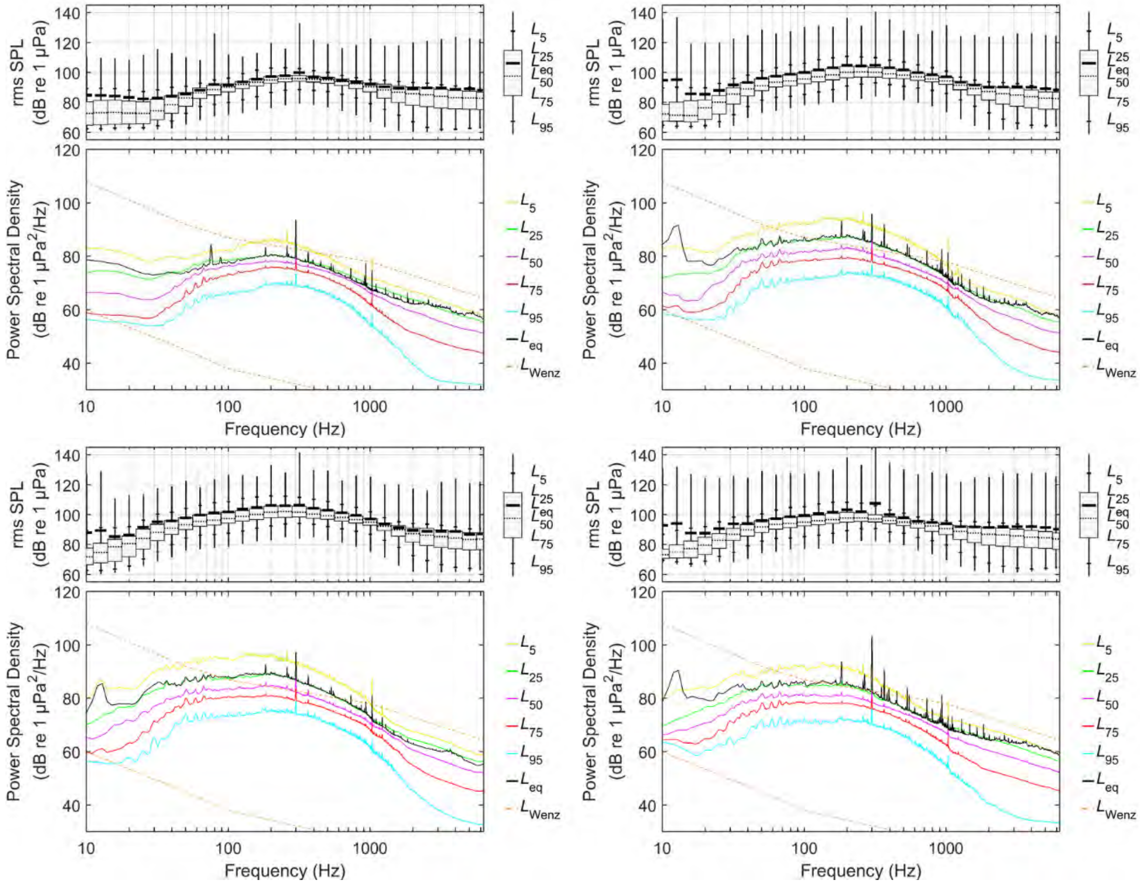

Figure B-8. 1/3-octave band sound pressure levels and percentile 1-min power spectral density levels for summer 2015 stations. (Top left) HSW1, (top right) HSW2, (bottom left) HSW3, and (bottom right) HSW4.

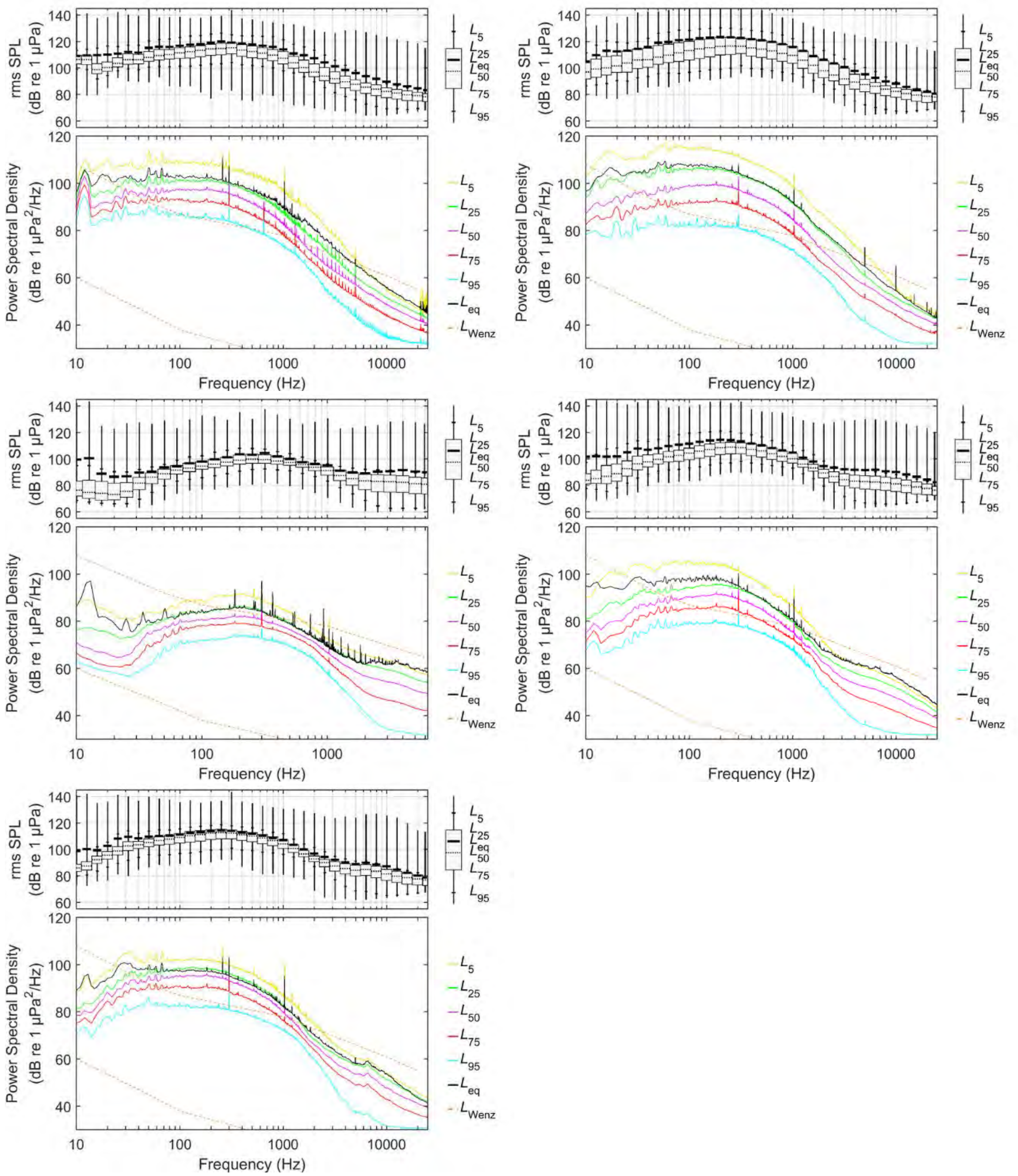

Figure B-9. 1/3-octave band sound pressure levels and percentile 1-min power spectral density levels for summer 2015 stations. (Top left) BG01, (top right) BG02, (middle left) BG03, (middle right) BGJ16, and (bottom) BGV16.

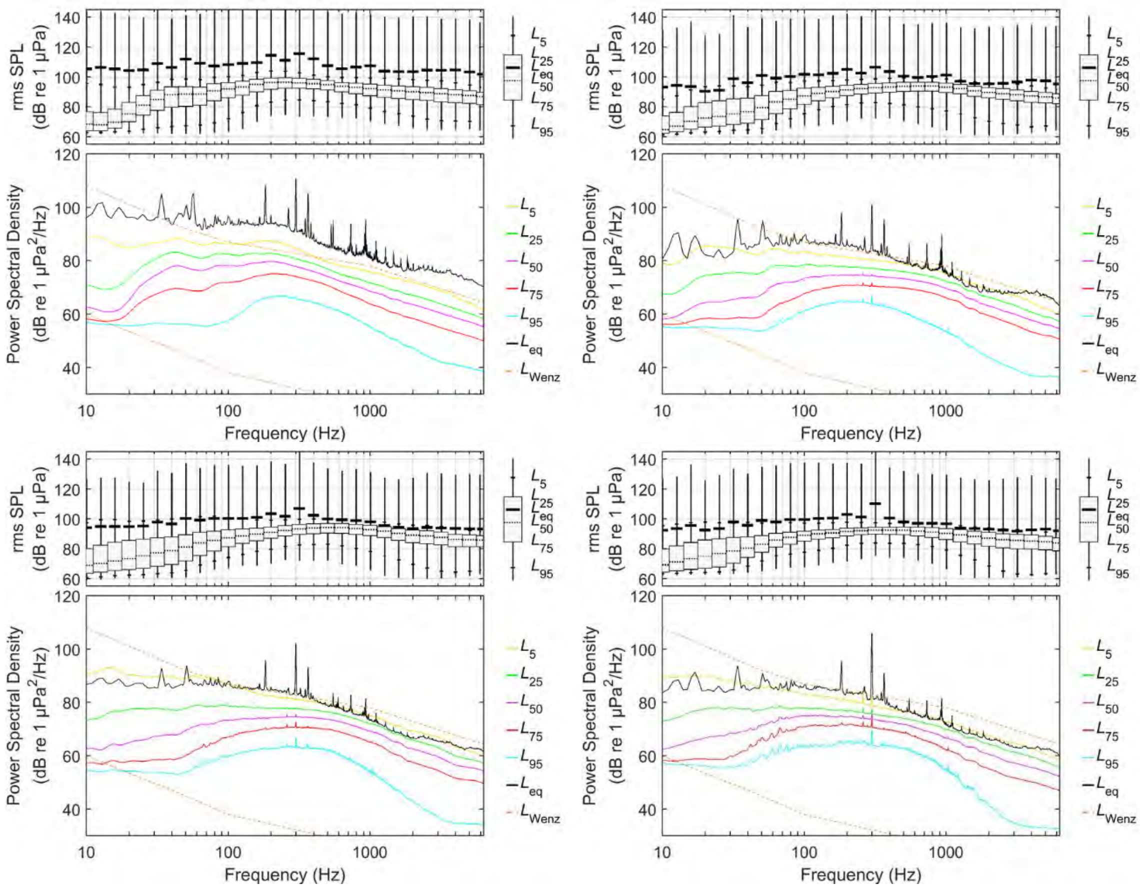

Figure B-10. 1/3-octave band sound pressure levels and percentile 1-min power spectral density levels for summer 2015 stations. (Top left) PL10, (top right) PL30, (bottom left) PL50, and (bottom right) PLN20.

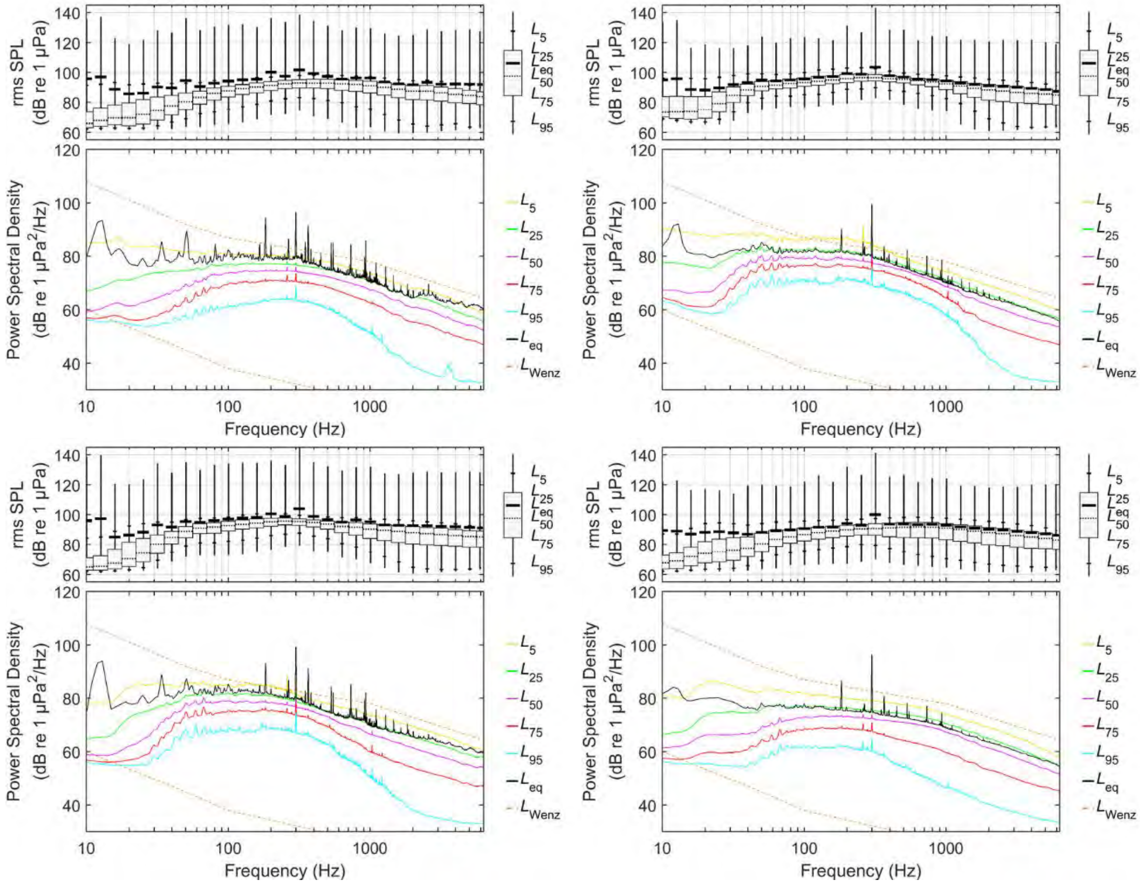

Figure B-11. 1/3-octave band sound pressure levels and percentile 1-min power spectral density levels for summer 2015 stations. (Top left) KL01, (top right) PLN40, (bottom left) PLN60, and (bottom right) PLN80.

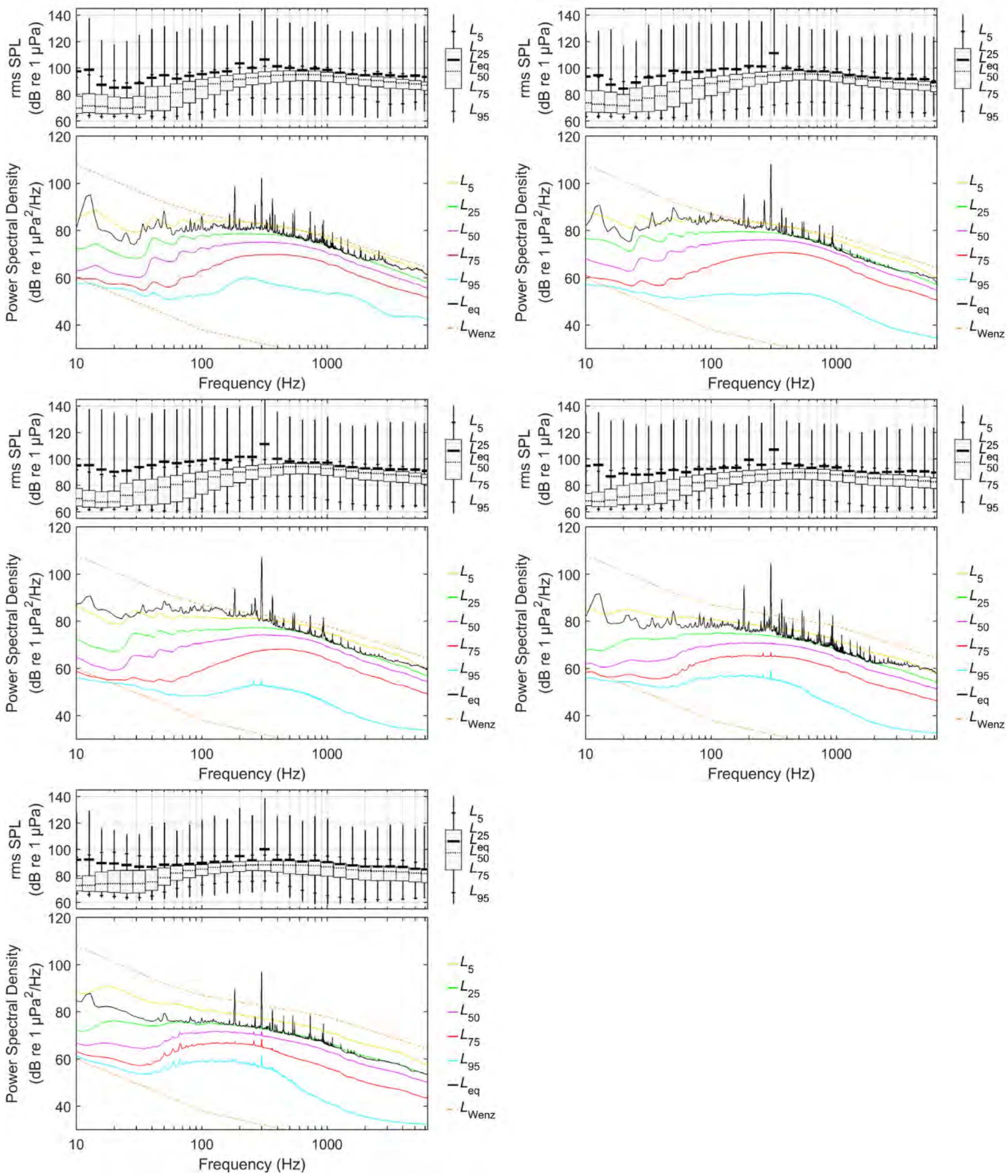

Figure B-12. 1/3-octave band sound pressure levels and percentile 1-min power spectral density levels for summer 2015 stations. (Top left) CL5, (top right) CL50, (middle left) CLN40, (middle right) CLN90B, and (bottom) CLN120B.

B.3.2. Broadband and Decade-Band Sound Pressure Levels and Spectrograms

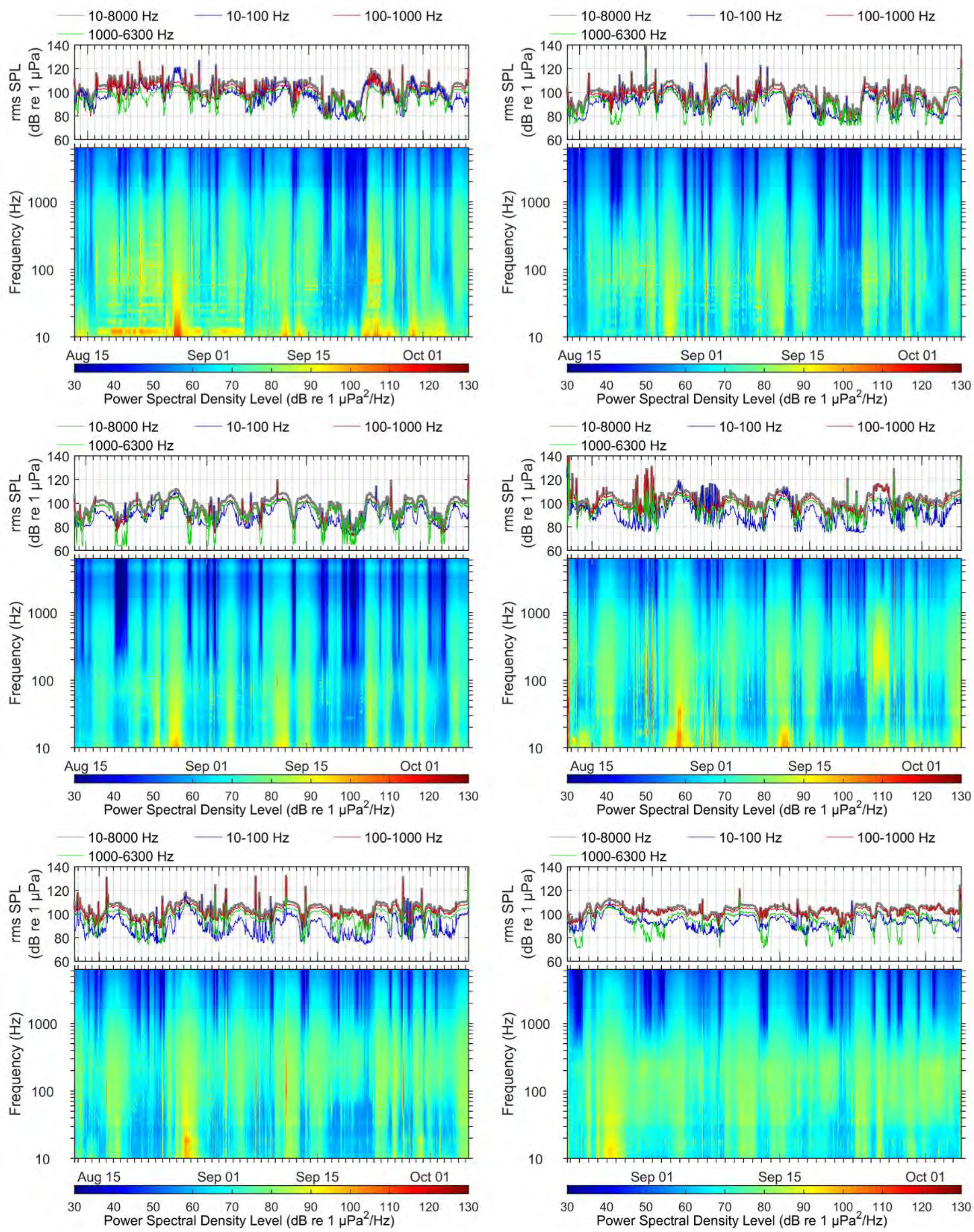

Figure B-13. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2015 stations. (Top left) B5, (top right) B15, (middle left) B30, (middle right) W10, (bottom left) W30, and (bottom right) W50.

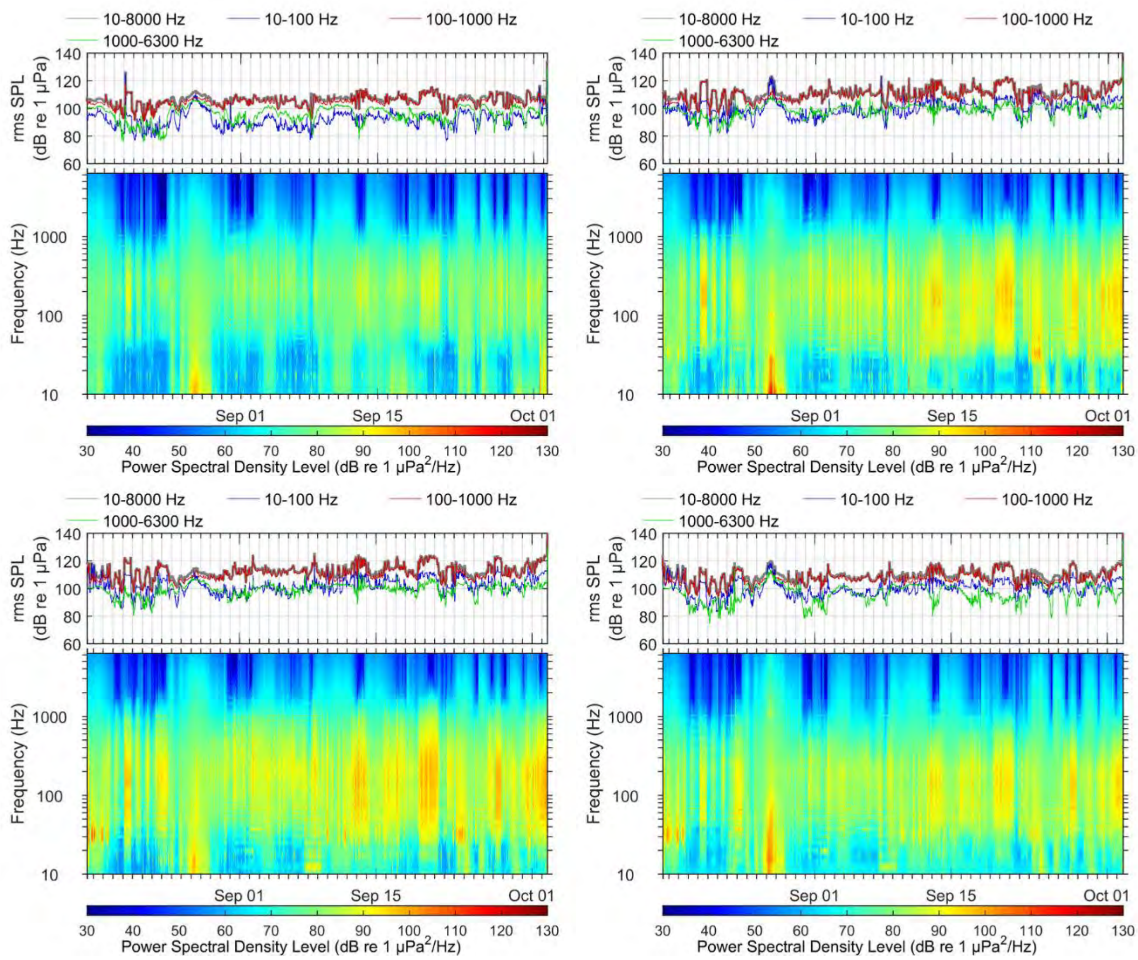

Figure B-14 Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2015 stations. (Top left) HSW1, (top right) HSW2, (bottom left) HSW3, and (bottom right) HSW4.

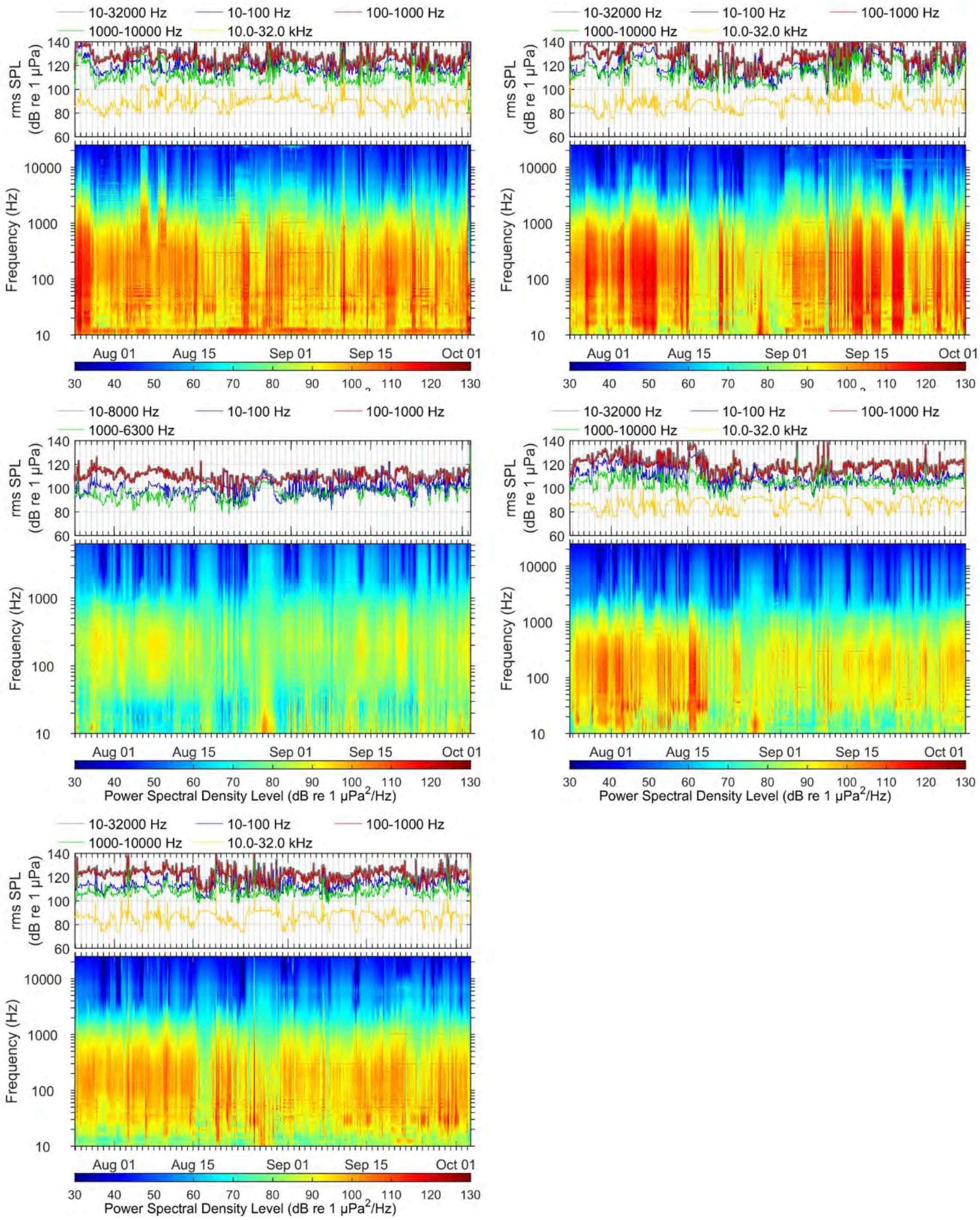

Figure B-15. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2015 stations. (Top left) BG01, (top right) BG02, (middle left) BG03, (middle right) BG_J16, and (bottom) BG_V16.

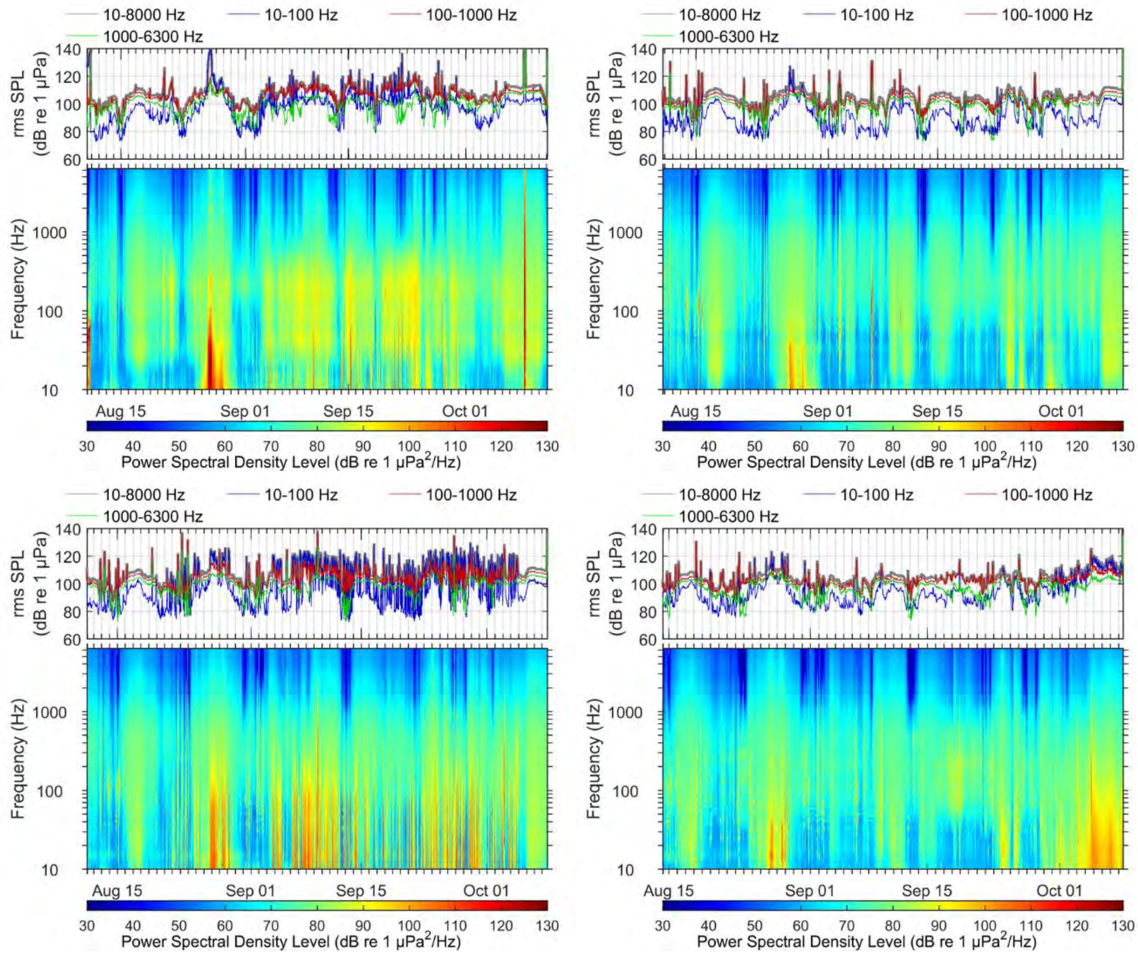

Figure B-16. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2015 stations. (Top left) PL10, (top right) PL30, (bottom left) PL50, and (bottom right) PLN20.

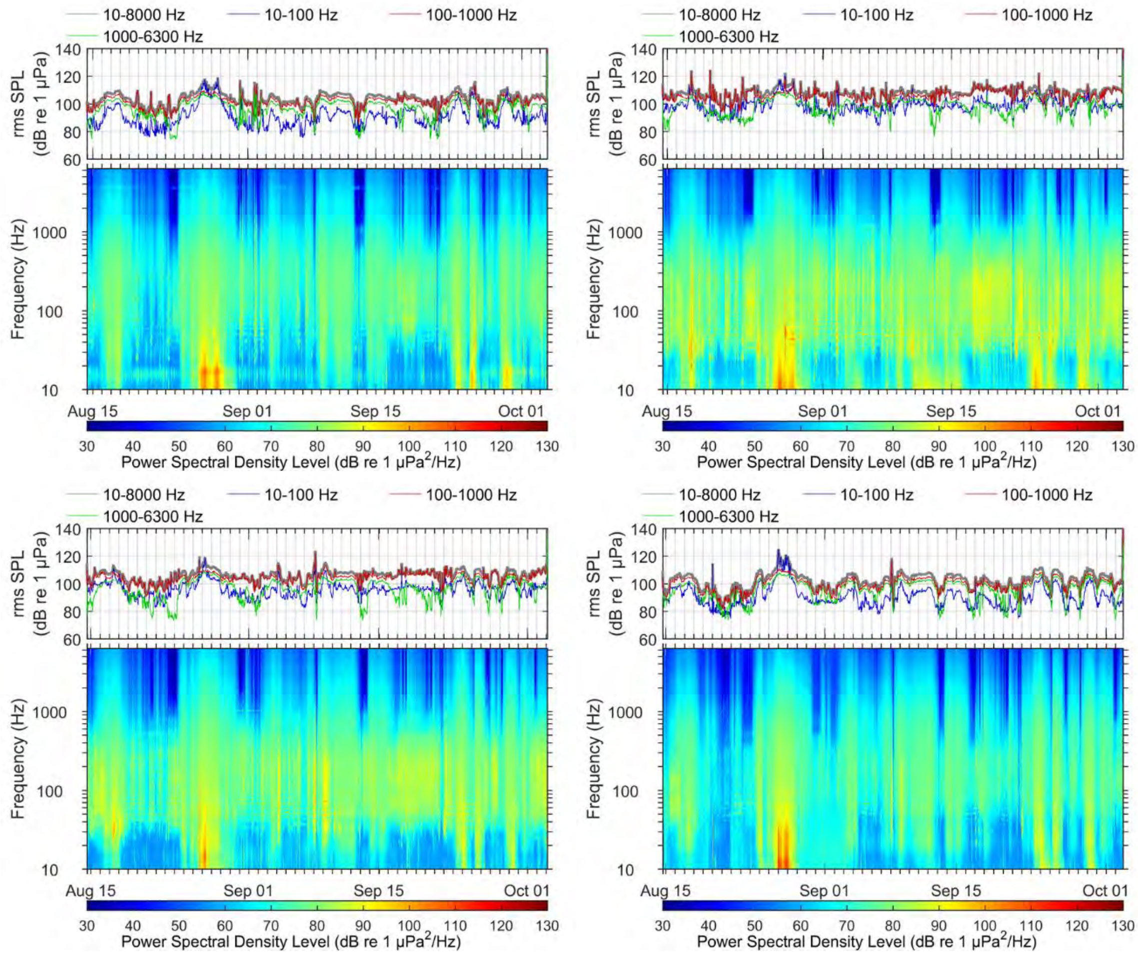

Figure B-17. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2015 stations. (Top left) KL01, (top right) PLN40, (bottom left) PLN60, and (bottom right) PLN80.

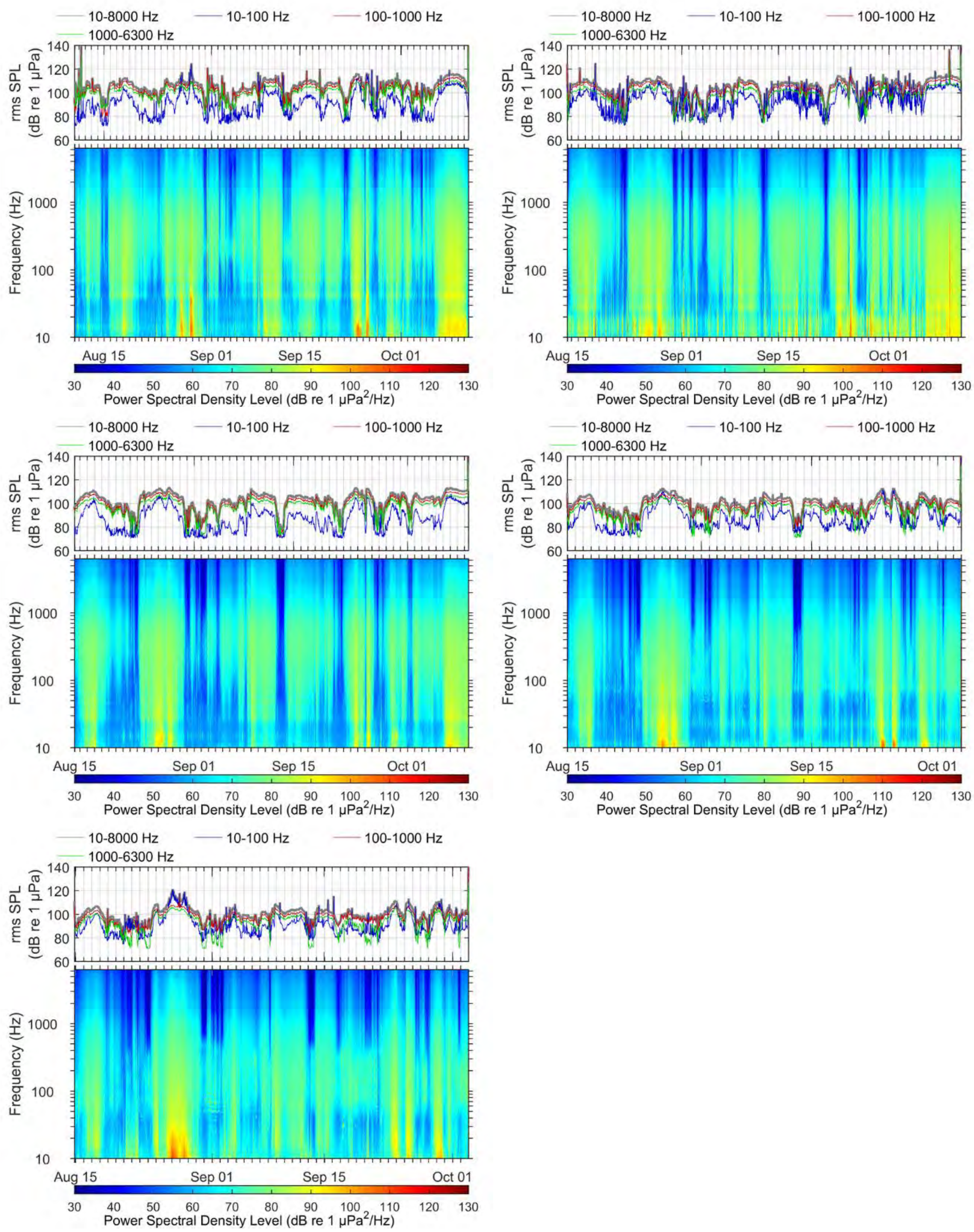

Figure B-18. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2014 stations. (Top left) CL5, (top right) CL50, (middle left) CLN40, (middle right) CLN90, and (bottom) CLN120.

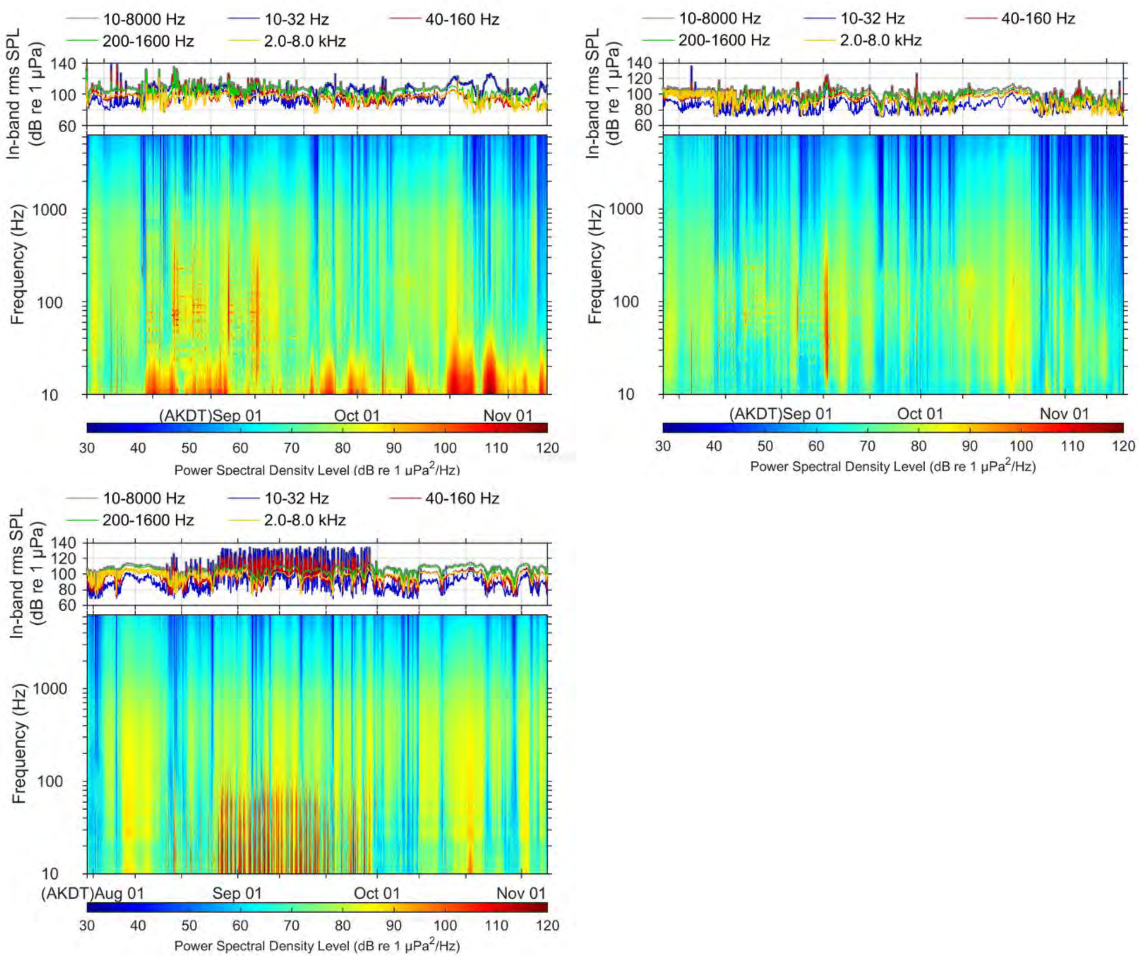

Figure B-19. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2014 stations. (Top left) B5, (top right) B15, and (bottom) CL50.

B.3.3. Daily Sound Exposure Level

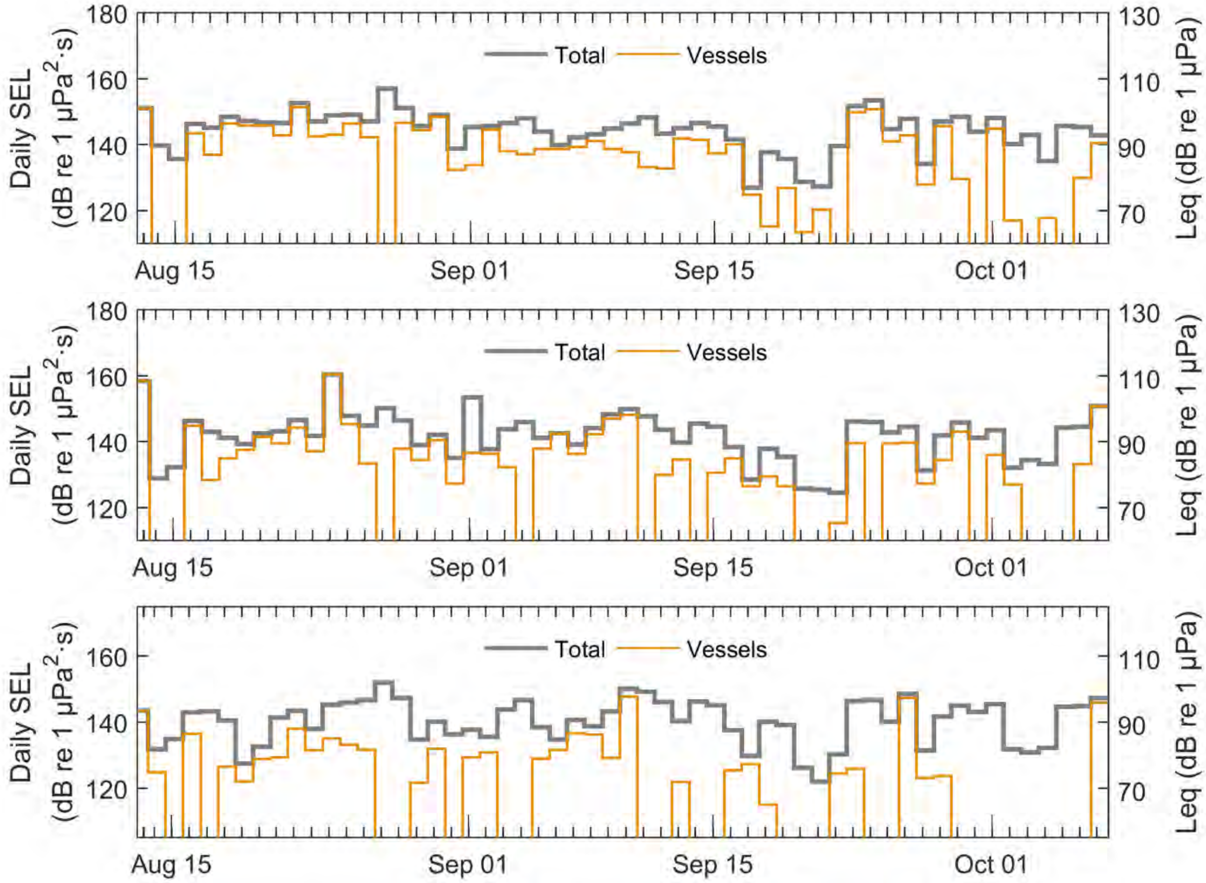

Figure B-20. Daily sound exposure level (SEL 24 h) distributions for summer 2015. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: B5, B15, and B30.

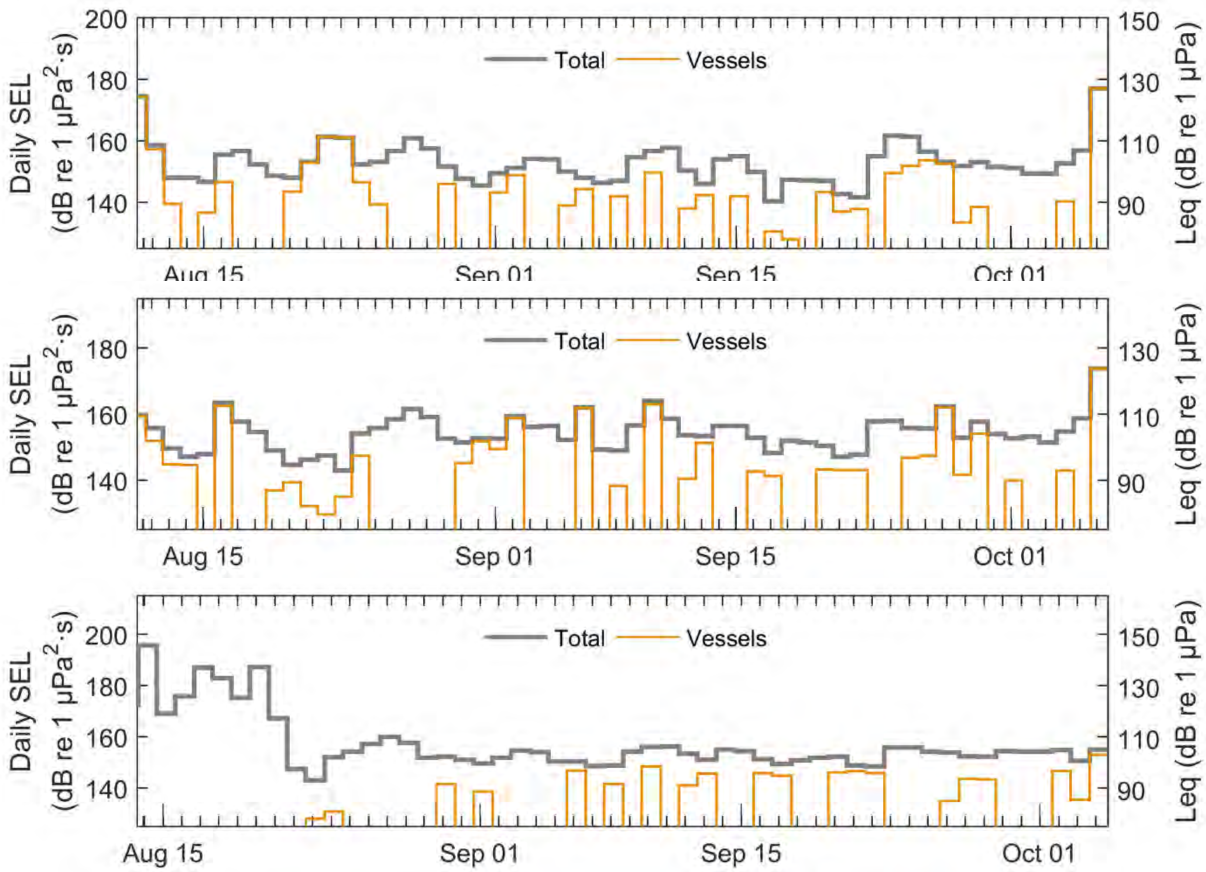

Figure B-21. Daily sound exposure level (SEL 24 h) distributions for summer 2015. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: W10, W30, and W50.

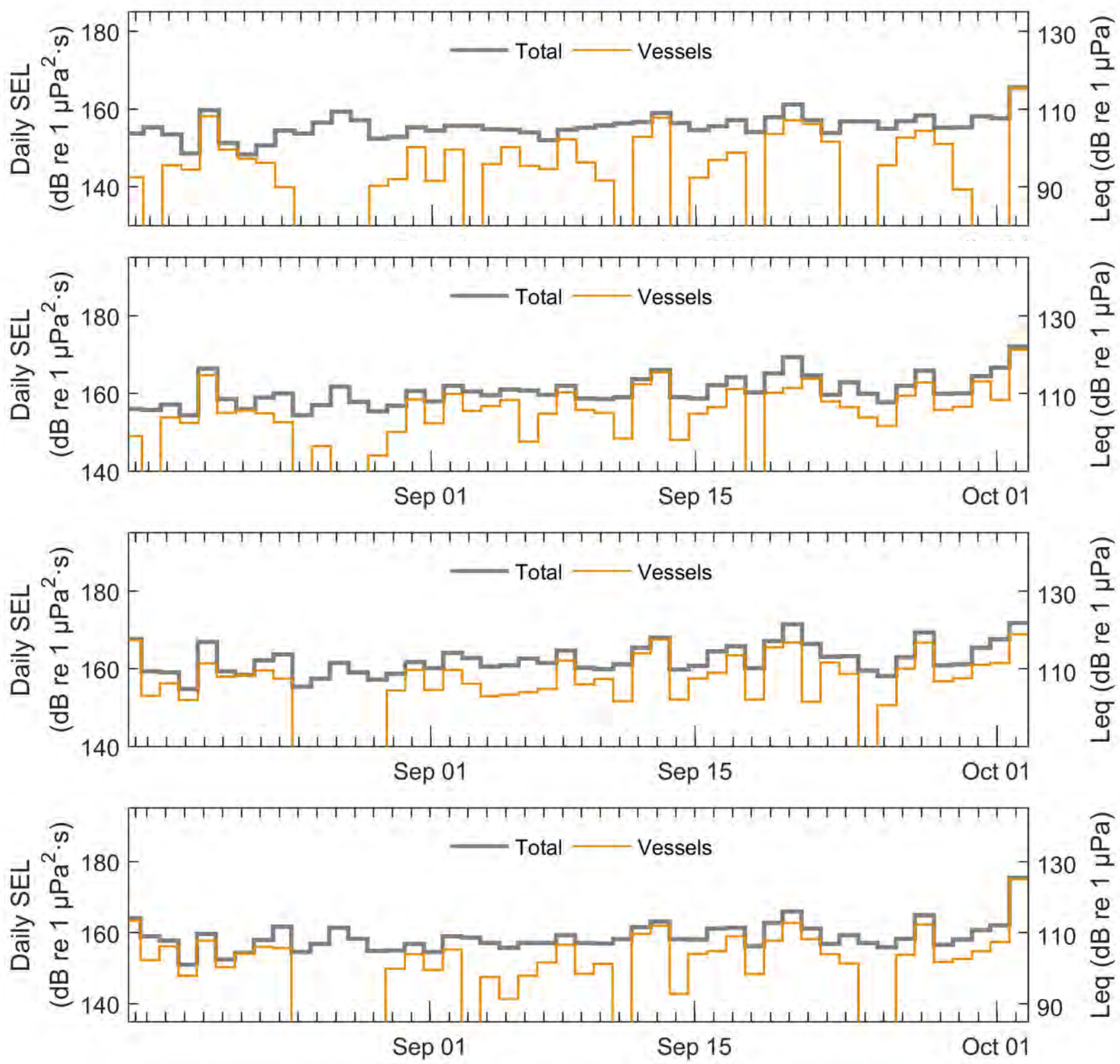

Figure B-22. Daily sound exposure level (SEL 24 h) distributions for summer 2015. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: HSW1, HSW2, HSW3, and HSW4.

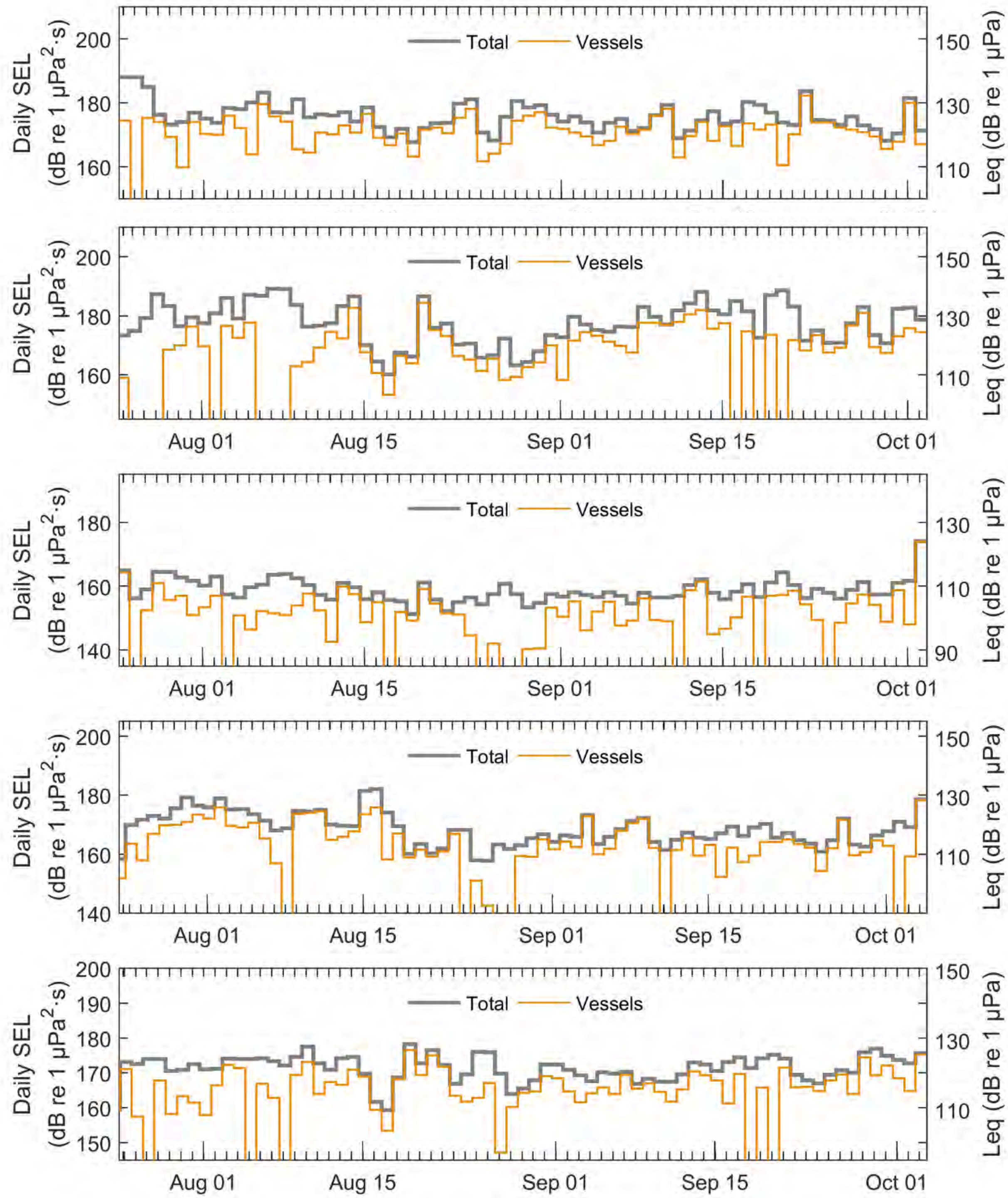

Figure B-23. Daily sound exposure level (SEL 24 h) distributions for summer 2015. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: BG01, BG02, BG03, BG_J16, and BG_V16.

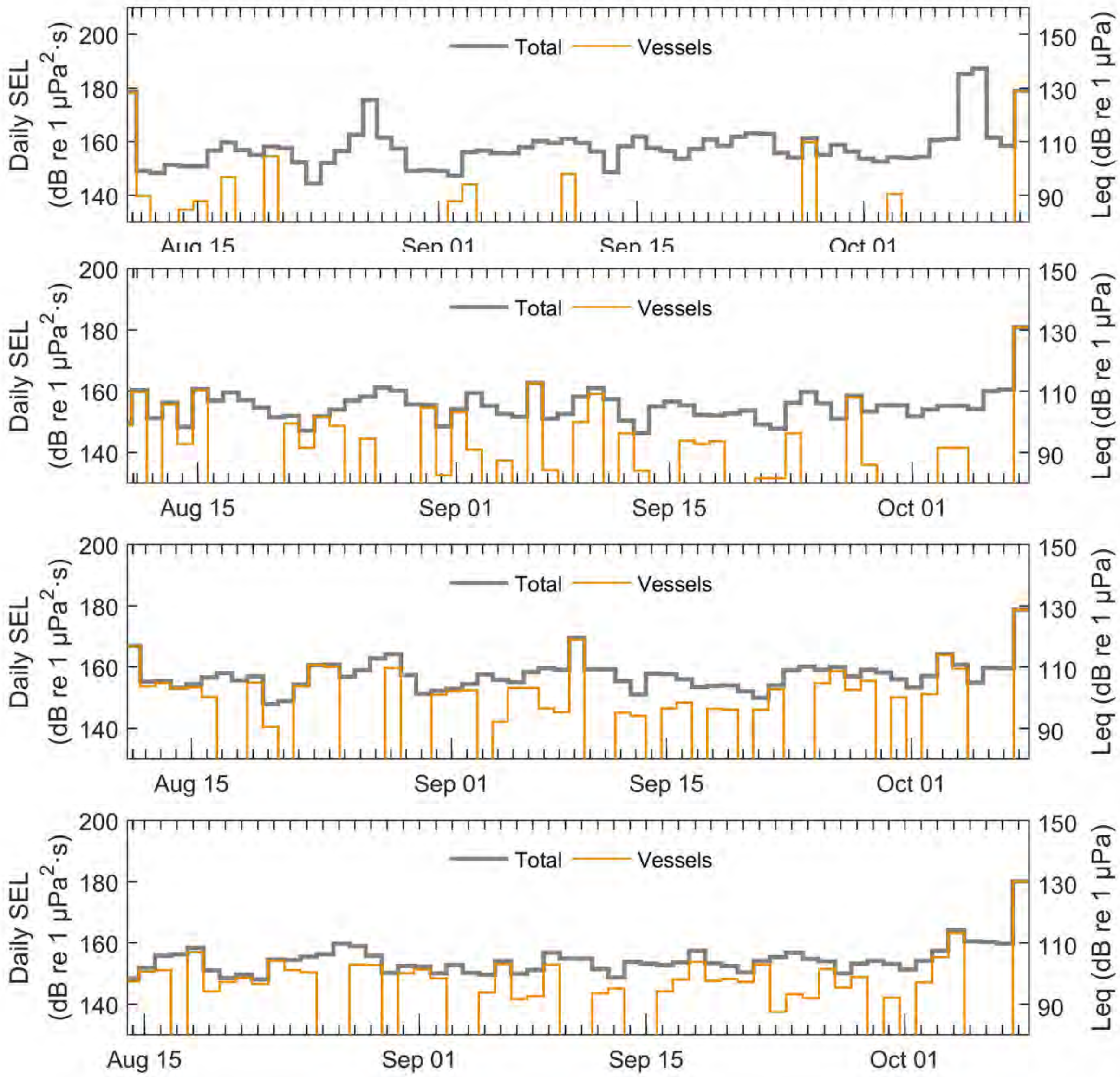

Figure B-24. Daily sound exposure level (SEL 24 h) distributions for summer 2015. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: PL10, PL30, PL50, and PLN20.

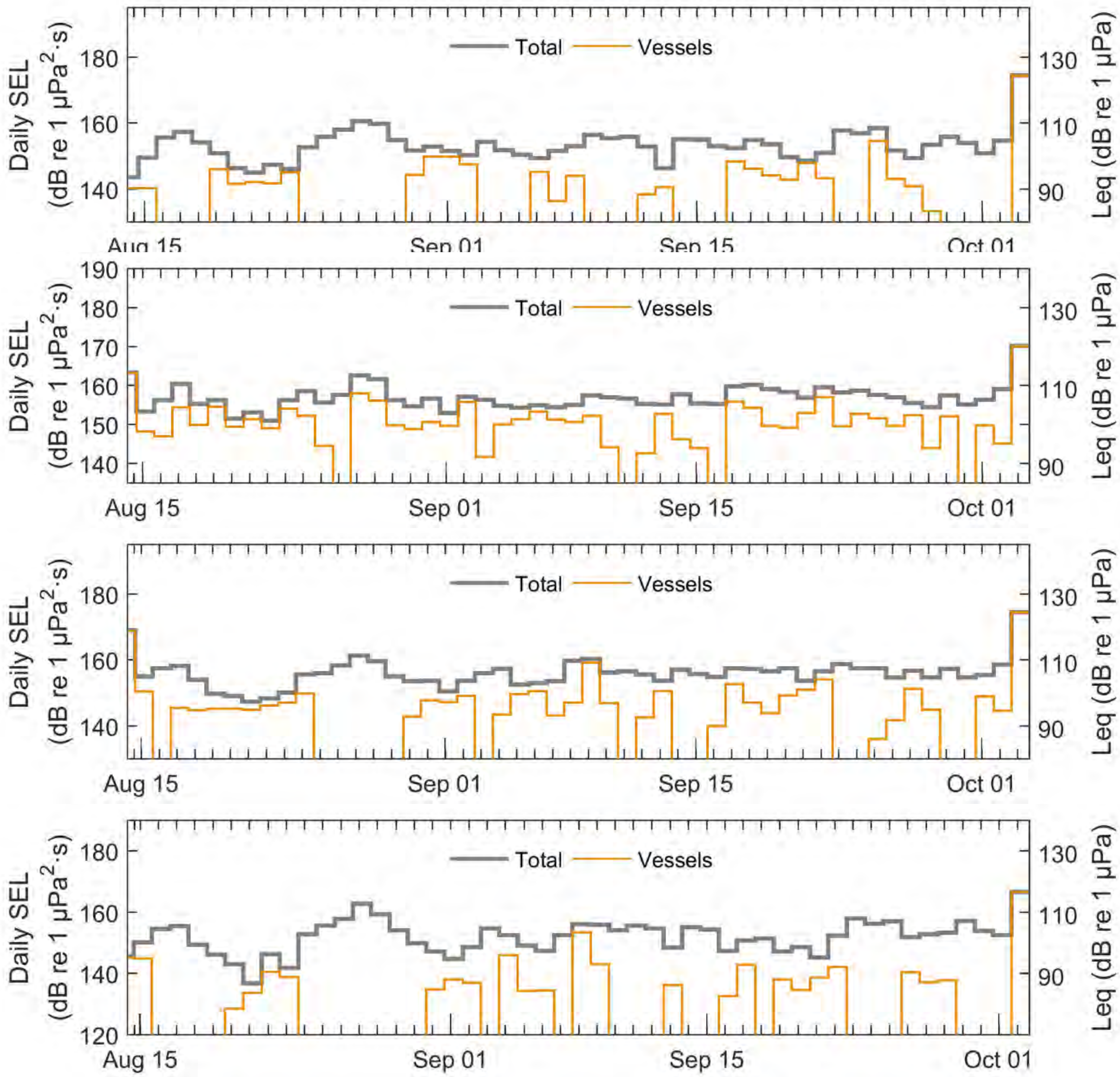

Figure B-25. Daily sound exposure level (SEL 24 h) distributions for summer 2015. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: KL01, PLN40, PLN60, and PLN80.

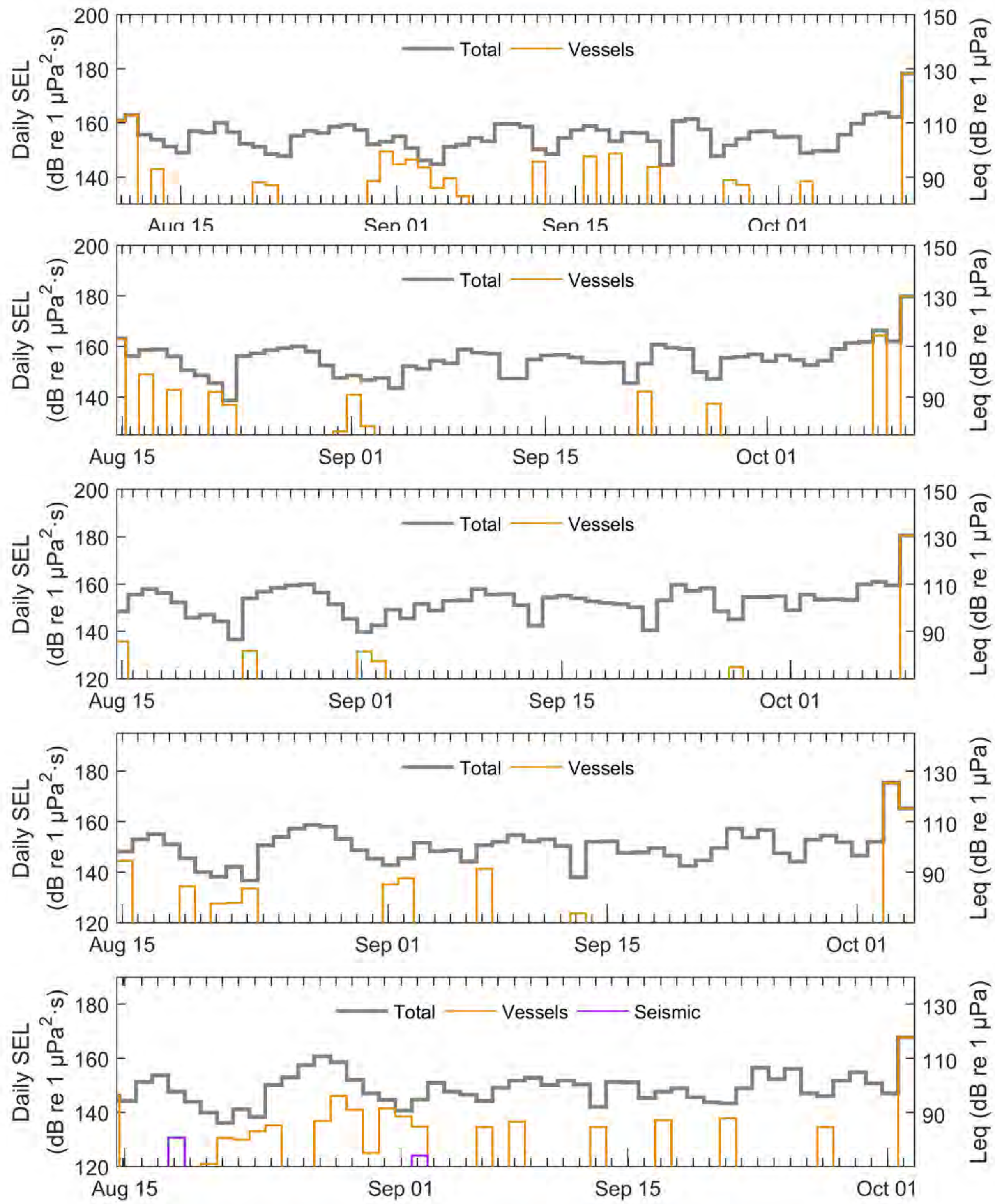

Figure B-26. Daily sound exposure level (SEL 24 h) distributions for summer 2015. The data were divided into total, vessel, and seismic classes. Note 24 h L_{eq} is 49.4 dB less than daily SEL. From top to bottom: CL5, CL50, CLN40, CLN90, and CLN120.

B.3.4. Vessel Noise Detection

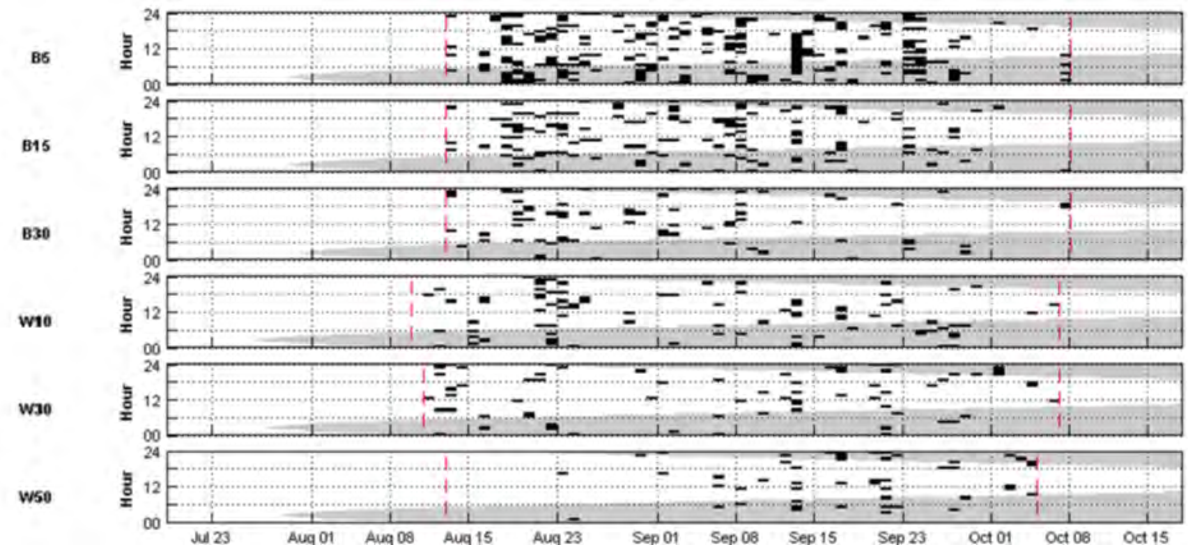

Figure B-27. Vessel detections each hour (vertical axis) versus date (horizontal axis) at six stations—B5 to W50—for summer 2015. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

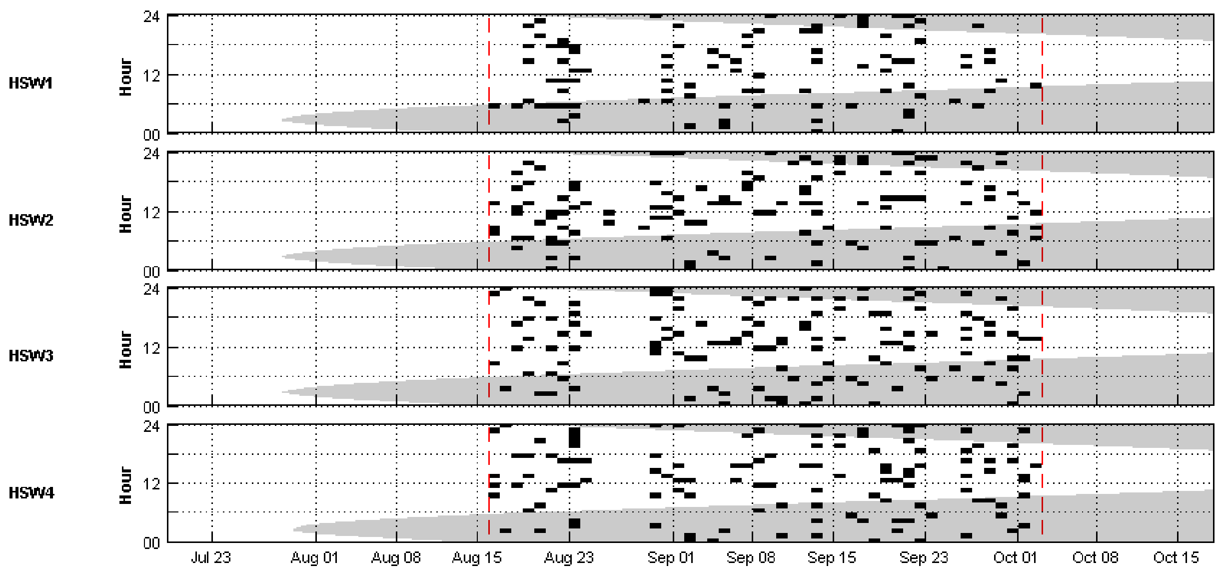

Figure B-28. Vessel detections each hour (vertical axis) versus date (horizontal axis) at four stations—HSW1 to HSW4—for summer 2015. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

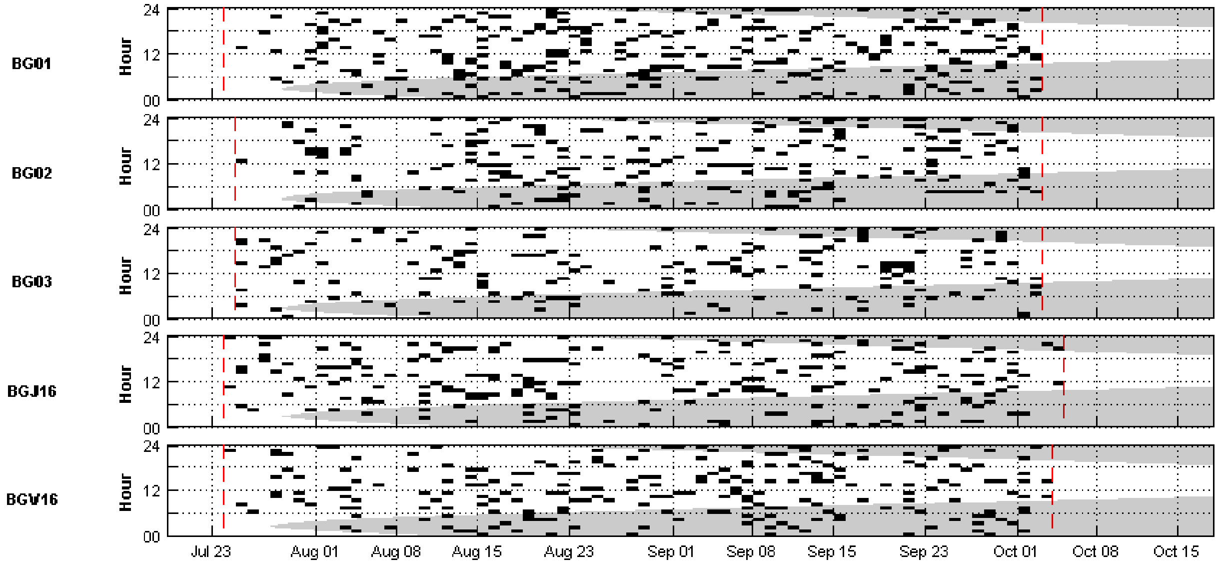

Figure B-29. Vessel detections each hour (vertical axis) versus date (horizontal axis) at five stations—BG01 to BG_V16—for summer 2015. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

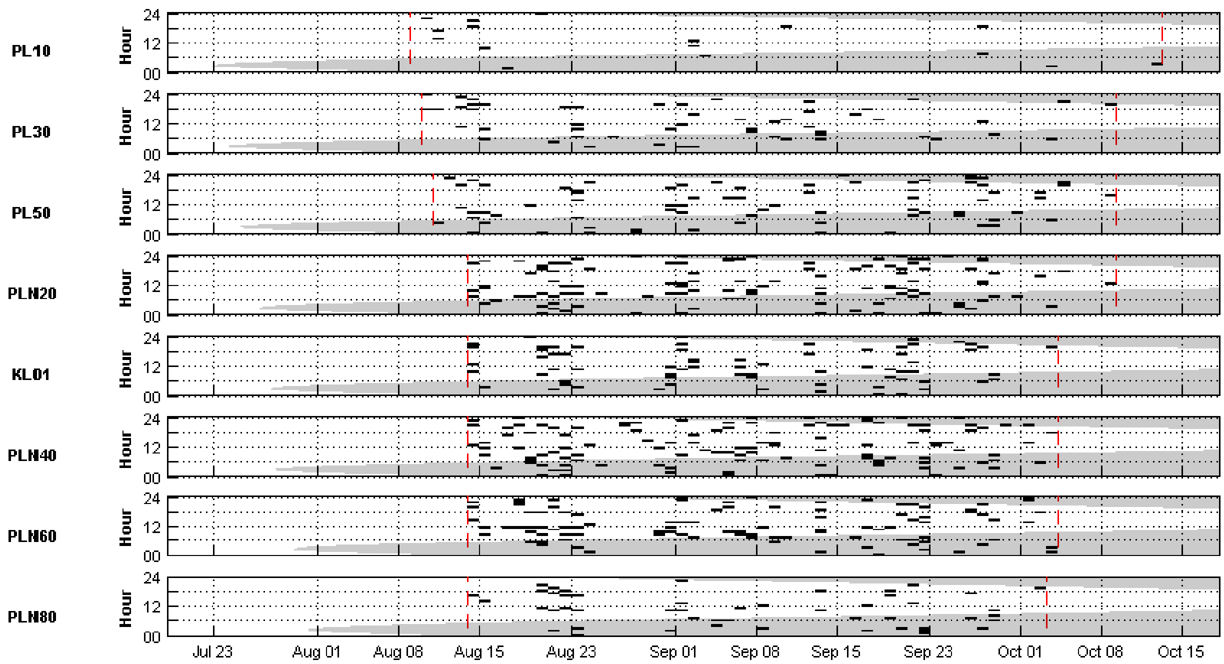

Figure B-30. Vessel detections each hour (vertical axis) versus date (horizontal axis) at eight stations—PL10 to PLN80—for summer 2015. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

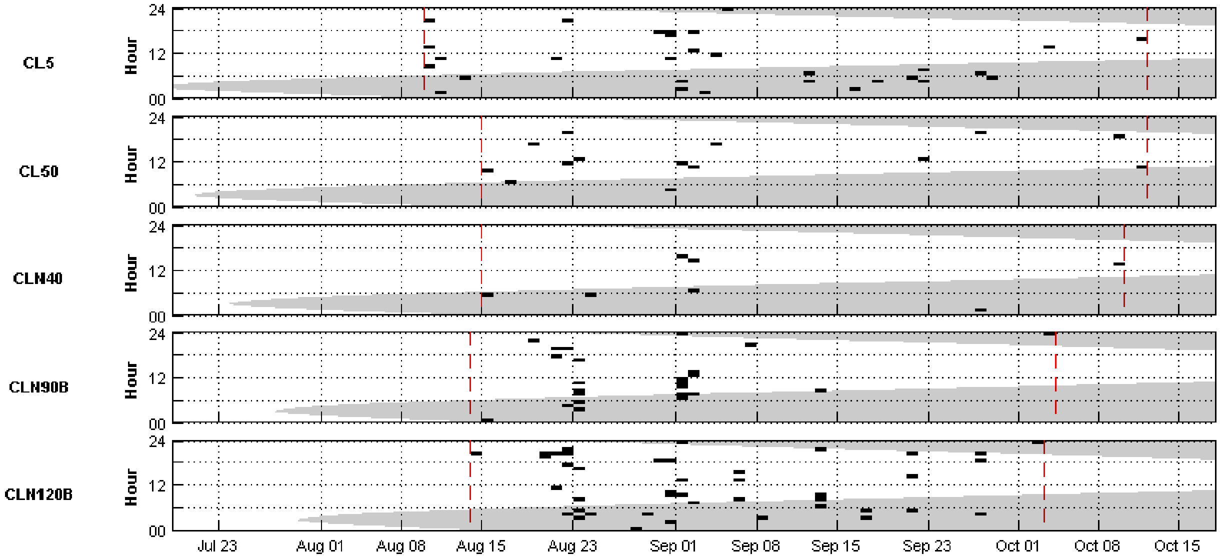

Figure B-31. Vessel detections each hour (vertical axis) versus date (horizontal axis) at five stations—CL5 to CLN120B—summer 2015. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates..

Appendix C. Marine Mammal Detection Results

Table C-1. Winter 2014–2015 bowhead call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number of days on which a call was detected manually for each recording station in the northeastern Chukchi Sea. The recorders operated for 5 min every 30 min.

Station	Record start	Fall 2014			Spring 2015			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
CL5	17 Oct	30 Oct	23 Jan	69	25 Mar	7 Jun	59	10 Aug
PL10	9 Oct	4 Nov	28 Nov	11				29 Nov
PL50	9 Oct	22 Oct	9 Jan	25	9 Apr	5 Jul	22	11 Aug
PLN40	13 Oct	14 Oct	9 Dec	36				9 Dec
W10	15 Oct	16 Oct	25 Nov	7	1 Apr	30 Jul	72	11 Aug
W50	16 Oct	18 Oct	6 Dec	17				27 Jan
WN40	12 Oct	--	--	0	--	--	0	30 Aug

-- No detections; blank cells mean that the recorders stopped earlier.

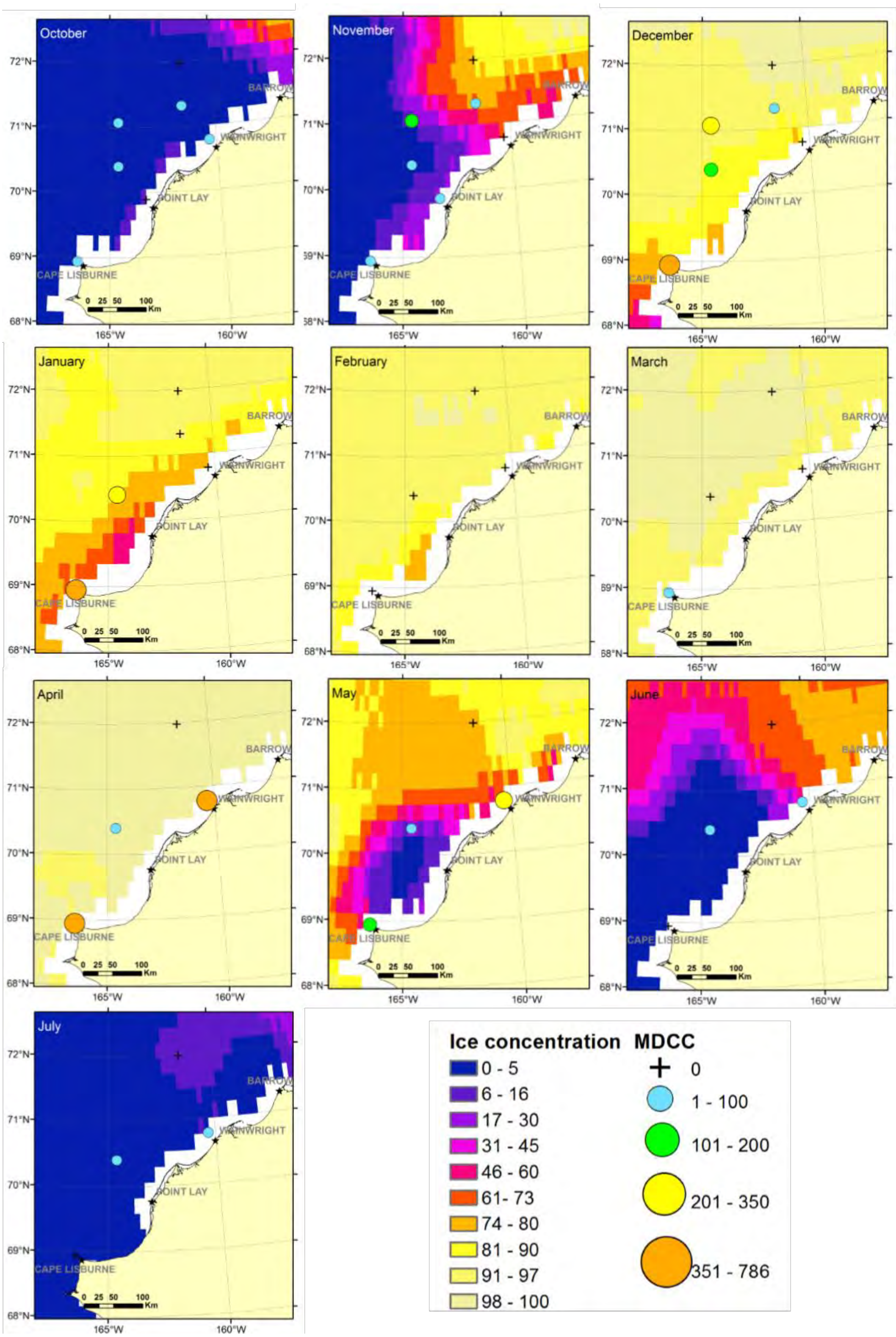

Figure C-1. Mean daily bowhead whale call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) for each month from 9 Oct 2014 to 31 Jul 2015 at all winter 2014–2015 stations. Ice data were from the middle of each month. Areas of complete ice coverage are shown in gray. Blue background indicates open water.

Table C-2. Summer 2015 bowhead call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percent of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections are omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B5	13 Aug	2 Sep	7 Oct	7 Oct	17	30.4
B15	13 Aug	13 Aug	7 Oct	7 Oct	34	60.7
B30	13 Aug	14 Aug	8 Oct	8 Oct	44	77.2
BG03	25 Jul	15 Sep	17 Sep	2 Oct	3	4.3
CLN120B	15 Aug	21 Aug	28 Sep	3 Oct	16	32.0
HSW1	16 Aug	15 Sep	19 Sep	2 Oct	3	6.3
HSW2	16 Aug	16 Sep	16 Sep	2 Oct	1	2.1
KL01	14 Aug	7 Sep	7 Sep	4 Oct	1	1.9
PLN60	14 Aug	22 Aug	25 Sep	3 Oct	14	27.5
PLN80	15 Aug	20 Aug	1 Oct	3 Oct	26	52.0
W10	11 Aug	13 Sep	21 Sep	6 Oct	2	3.5
W30	11 Aug	13 Sep	22 Sep	6 Oct	6	10.5
W50	14 Aug	6 Sep	23 Sep	5 Oct	11	20.0

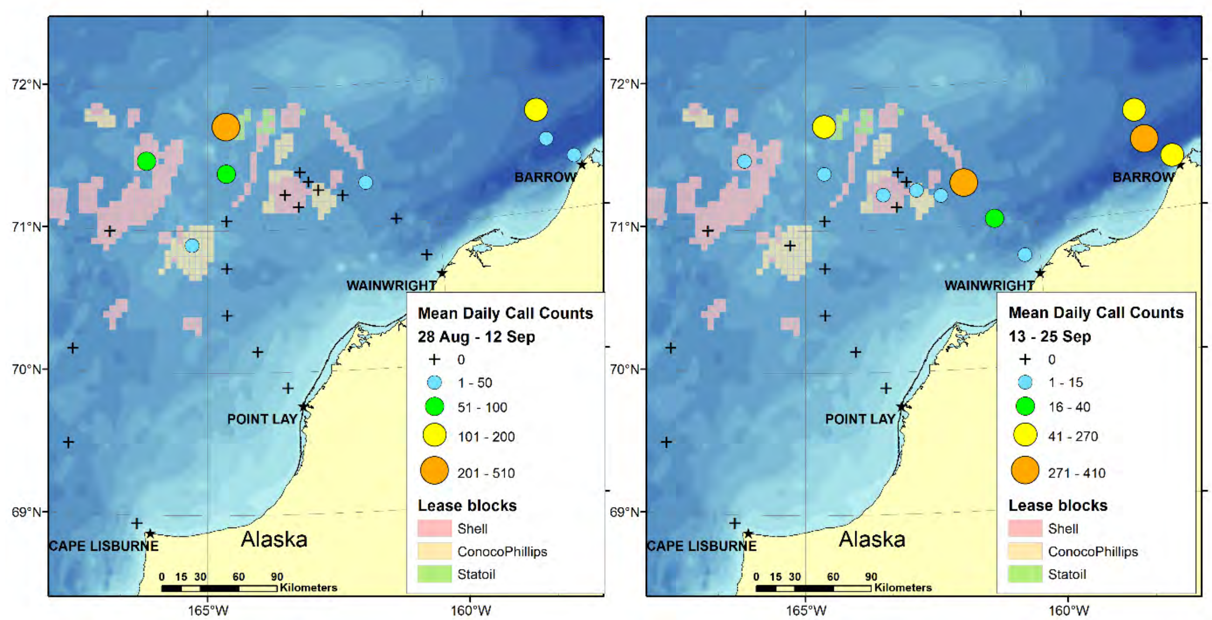

Figure C-2. Mean daily bowhead whale call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) from 28 Aug to 12 Sep and from 13 to 25 Sep at all summer 2015 stations in the northeastern Chukchi Sea.

Table C-3. Winter 2014–2015 walrus call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number of days on which a call was detected manually for each recording station in the northeastern Chukchi Sea. The recorders operated for 5 min every 30 min.

Station	Record start	Fall 2014			Spring 2015			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
CL5	17 Oct	23 Oct	31 Oct	4	7 Jun	10 Jun	3	10 Aug
PL10	9 Oct	10 Oct	13 Nov	14				29 Nov
PL50	9 Oct	--	--	0	4 Jun	26 Jul	30	11 Aug
PLN40	13 Oct	27 Oct	1 Dec	3				9 Dec
W10	15 Oct	27 Oct	13 Nov	7	1 May	10 Aug	28	11 Aug
W50	16 Oct	1 Nov	1 Dec	4				27 Jan
WN40	12 Oct	--	--	0	8 Jun	30 Aug	64	30 Aug

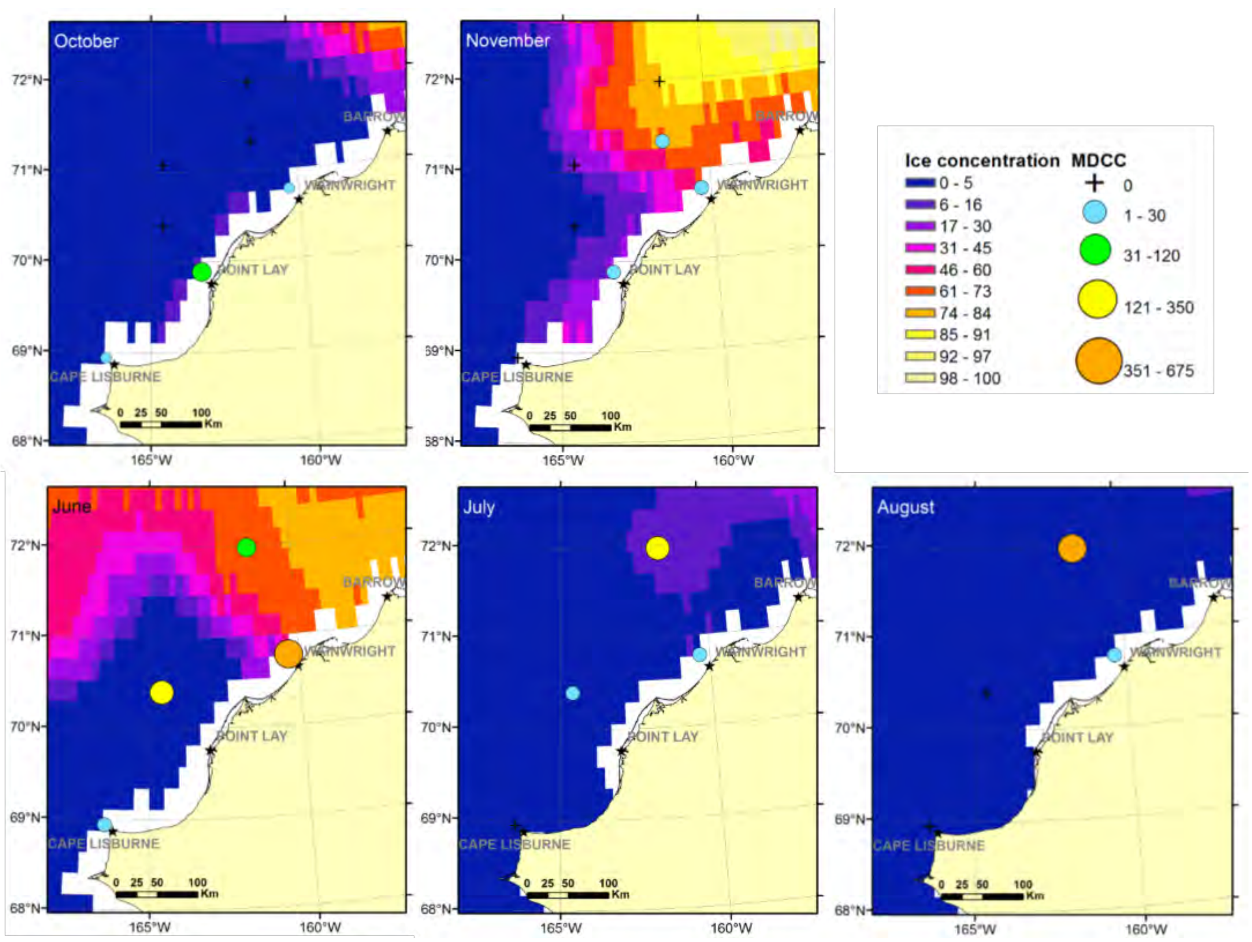

Figure C-3. Mean daily walrus call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) for each month from 9 Oct 2014 to 30 Nov 2014 and from 1 Jun to 30 Aug 2015 at all winter 2014–2015 stations. Ice data were from the middle of each month. Areas of complete ice coverage are shown in gray. Blue background indicates open water.

Table C-4. Summer 2015 walrus call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percent of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections are omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B5	13 Aug	4 Oct	4 Oct	7 Oct	1	1.8
B15	13 Aug	14 Aug	4 Oct	7 Oct	7	12.5
B30	13 Aug	19 Aug	4 Oct	8 Oct	12	21.1
BG03	25 Jul	12 Aug	1 Oct	2 Oct	35	50.0
CL5	10 Aug	14 Aug	11 Oct	11 Oct	53	84.1
CL50	15 Aug	21 Aug	3 Oct	11 Oct	16	27.6
CLN40	15 Aug	19 Aug	5 Oct	9 Oct	11	19.6
CLN90B	15 Aug	20 Aug	22 Sep	4 Oct	14	27.5
CLN120B	15 Aug	19 Aug	2 Oct	3 Oct	21	42.0
HSW1	16 Aug	16 Aug	1 Oct	2 Oct	34	70.8
HSW2	16 Aug	18 Aug	26 Sep	2 Oct	16	33.3
HSW3	16 Aug	17 Aug	30 Sep	2 Oct	17	35.4
HSW4	16 Aug	19 Aug	19 Sep	2 Oct	12	25.0
KL01	14 Aug	21 Aug	3 Oct	4 Oct	8	15.4
PL10	10 Aug	11 Aug	12 Oct	12 Oct	63	98.4
PL30	11 Aug	14 Aug	7 Oct	9 Oct	28	46.7
PL50	11 Aug	22 Aug	26 Sep	9 Oct	11	18.3
PLN20	14 Aug	19 Aug	8 Oct	8 Oct	11	19.6
PLN40	14 Aug	21 Aug	21 Sep	4 Oct	3	5.8
PLN60	14 Aug	20 Aug	1 Oct	3 Oct	15	29.4
PLN80	15 Aug	15 Aug	2 Oct	3 Oct	22	44.0
W10	11 Aug	14 Aug	3 Oct	6 Oct	33	57.9
W30	11 Aug	14 Aug	4 Oct	6 Oct	34	59.6
W50	14 Aug	14 Aug	4 Oct	5 Oct	45	81.8

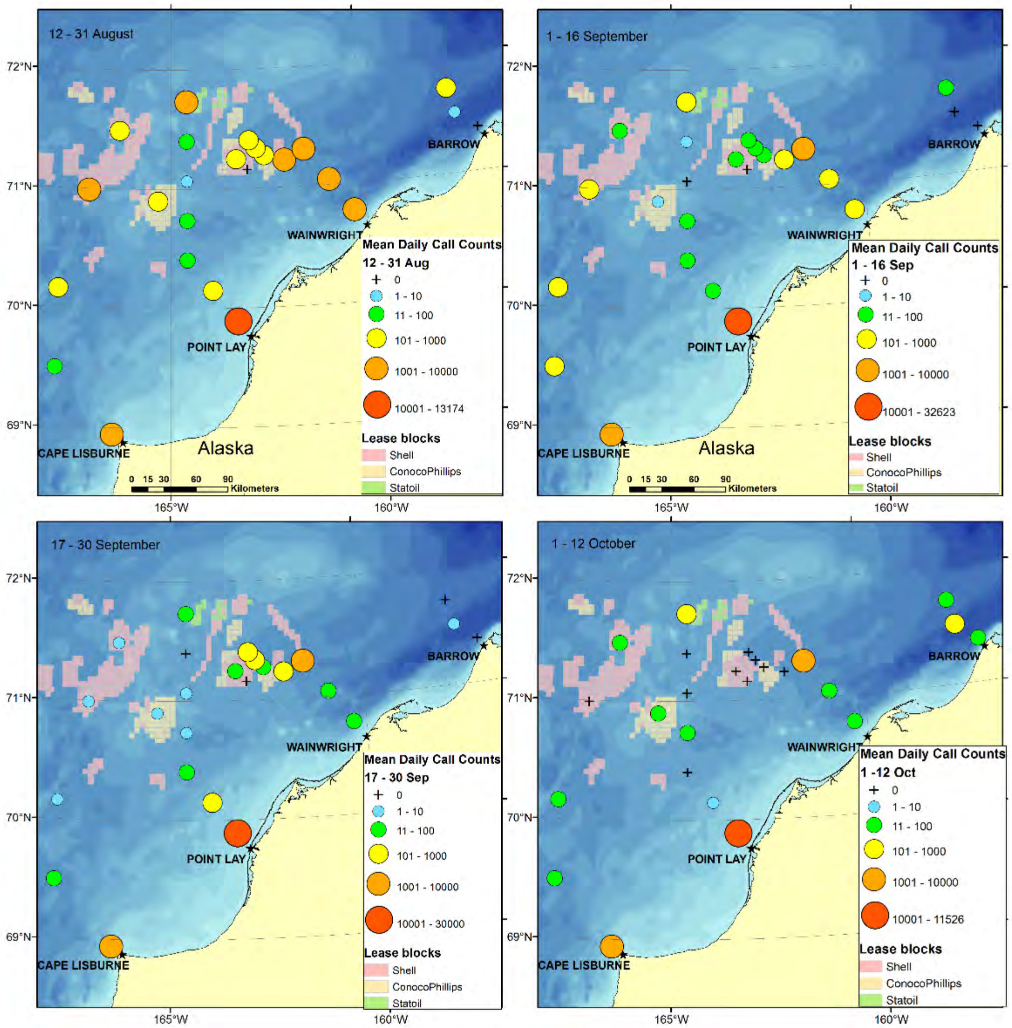

Figure C-4. Mean daily walrus call counts in the northeastern Chukchi Sea from (top left) 12 to 31 Aug, (top right) 1 to 16 Sep, (bottom left) 17 to 30 Sep, and (bottom right) 1 to12 Oct 2015.

Table C-5. Winter 2014–2015 beluga whale call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number of days on which a call was detected manually for each recording station in the northeastern Chukchi Sea. The recorders operated for 5 min every 30 min.

Station	Record start	Fall 2014			Spring 2015			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
CL5	17 Oct	3 Nov	30 Nov	8	25 Mar	24 May	49	10 Aug
PL10	9 Oct	--	--	0				29 Nov
PL50	9 Oct	7 Nov	29 Nov	9	8 Apr	6 Jul	41	11 Aug
PLN40	13 Oct	31 Oct	16 Nov	12				9 Dec
W10	15 Oct	5 Nov	26 Nov	7	18 Apr	30 Jul	42	11 Aug
W50	16 Oct	1 Nov	16 Nov	3				27 Jan
WN40	12 Oct	--	--	0	23 Apr	8 Jul	13	30 Aug

-- No detections; blank cells mean that the recorders stopped earlier.

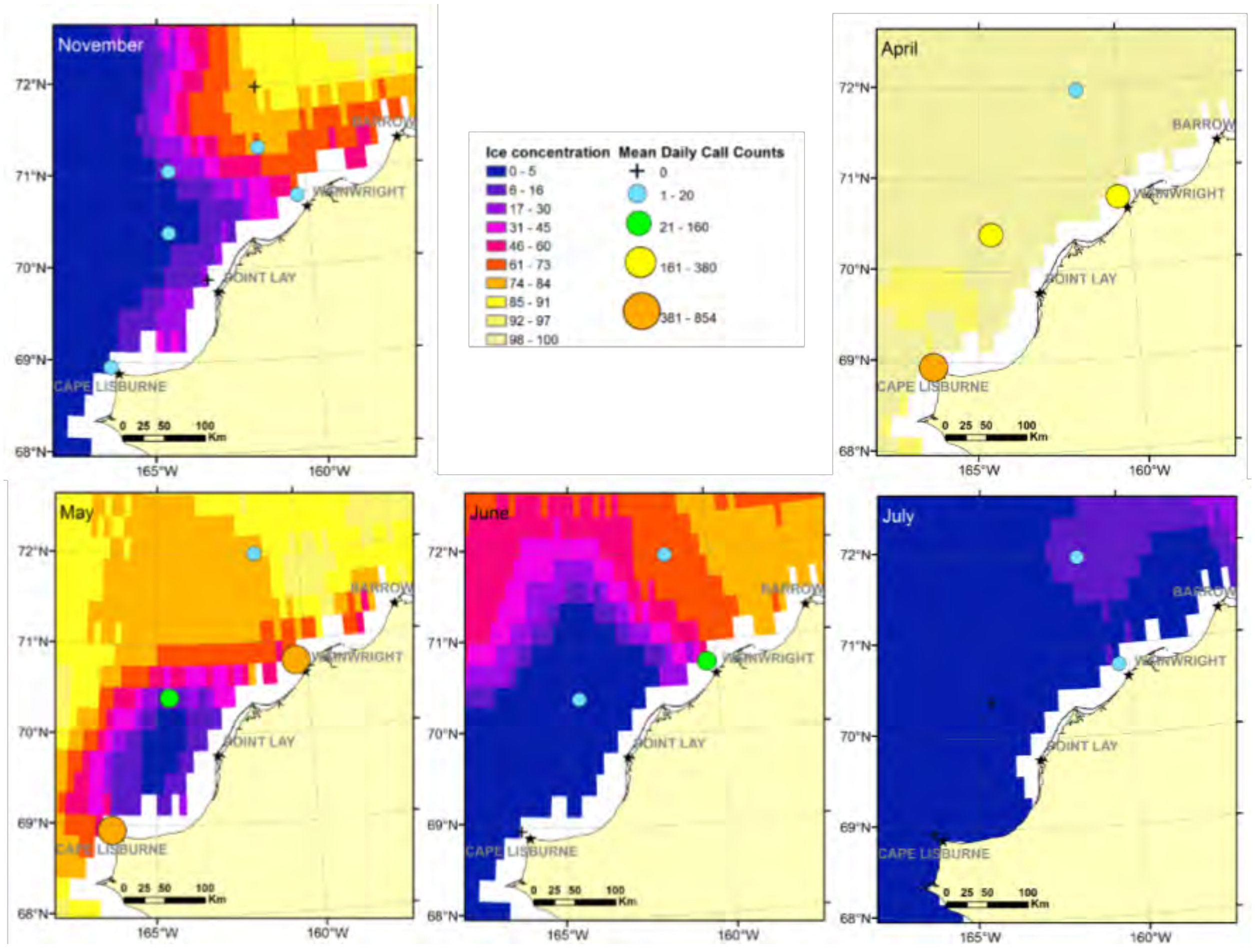

Figure C-5. Mean daily beluga whale call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) for each month in November 2014 and from 1 April to 31 July 2015 at all winter 2014–2015 stations. Ice data were from the middle of each month. Areas of complete ice coverage are shown in gray. Blue background indicates open water.

Table C-6. Summer 2015 beluga call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percent of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections are omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B5	13 Aug	18 Sep	28 Sep	7 Oct	6	10.7
B15	13 Aug	17 Sep	28 Sep	7 Oct	5	8.9
B30	13 Aug	17 Sep	4 Oct	8 Oct	4	7.0
BG02	25 Jul	28 Jul	29 Jul	6 Aug	2	2.9
HSW4	16 Aug	1 Sep	1 Sep	2 Oct	1	2.1
PLN80	15 Aug	2 Oct	2 Oct	3 Oct	1	2.0

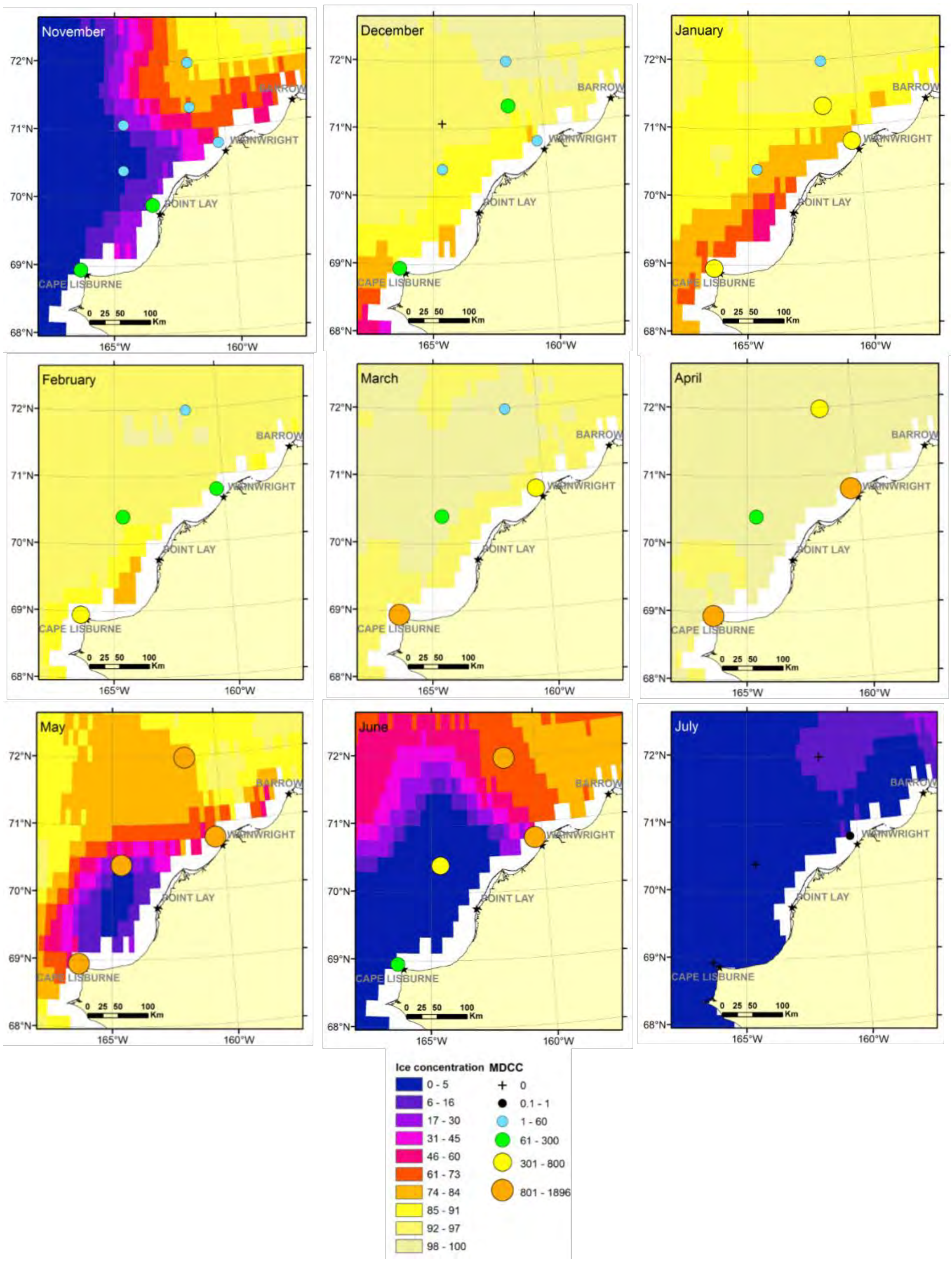

Figure C-6. Mean daily bearded seal call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) for each month from 9 Oct 2014 to 31 Jul 2015 at all winter 2014–2015 stations. Ice data were from the middle of each month. Areas of complete ice coverage are shown in gray. Blue background indicates open water.

Table C-7. Winter 2014–2015 bearded seal call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number of days on which a call was detected manually for each recording station in the northeastern Chukchi Sea. The recorders operated for 5 min every 30 min.

Station	Record start	First detection	Last detection	Record end	Detection days
CL5	17 Oct	21 Oct	13 Jun	10 Aug	198
PL10	9 Oct	11 Oct	28 Nov	29 Nov	24
PL50	9 Oct	7 Nov	22 Jun	11 Aug	165
PLN40	13 Oct	14 Oct	17 Nov	9 Dec	6
W10	15 Oct	5 Nov	30 Jul	11 Aug	204
W50	16 Oct	1 Nov	27 Jan	27 Jan	64
WN40	12 Oct	28 Oct	29 Jun	30 Aug	180

Table C-8. Summer 2015 bearded seal call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percent of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections are omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B5	13 Aug	2 Sep	5 Oct	7 Oct	18	32.1
B15	13 Aug	13 Aug	4 Oct	7 Oct	19	33.9
B30	13 Aug	1 Sep	5 Oct	8 Oct	12	21.1
CL5	10 Aug	3 Oct	4 Oct	11 Oct	2	3.2
CL50	15 Aug	22 Sep	4 Oct	11 Oct	4	6.9
CLN40	15 Aug	23 Aug	2 Oct	9 Oct	13	23.2
CLN90B	15 Aug	24 Aug	27 Sep	4 Oct	4	7.8
CLN120B	15 Aug	24 Aug	2 Oct	3 Oct	16	32.0
HSW1	16 Aug	7 Sep	30 Sep	2 Oct	6	12.5
HSW2	16 Aug	22 Sep	22 Sep	2 Oct	1	2.1
HSW3	16 Aug	6 Sep	1 Oct	2 Oct	4	8.3
HSW4	16 Aug	18 Aug	30 Sep	2 Oct	4	8.3
KL01	14 Aug	21 Sep	3 Oct	4 Oct	2	3.8
PL10	10 Aug	25 Sep	4 Oct	12 Oct	3	4.7
PL30	11 Aug	30 Sep	30 Sep	9 Oct	1	1.7
PL50	11 Aug	24 Aug	28 Sep	9 Oct	6	10.0
PLN20	14 Aug	7 Sep	7 Oct	8 Oct	14	25.0
PLN40	14 Aug	2 Oct	2 Oct	4 Oct	1	1.9
PLN60	14 Aug	17 Aug	2 Oct	3 Oct	19	37.3
PLN80	15 Aug	20 Aug	2 Oct	3 Oct	26	52.0
W10	11 Aug	21 Aug	6 Oct	6 Oct	24	42.1
W30	11 Aug	22 Aug	5 Oct	6 Oct	15	26.3
W50	14 Aug	7 Sep	4 Oct	5 Oct	13	23.6

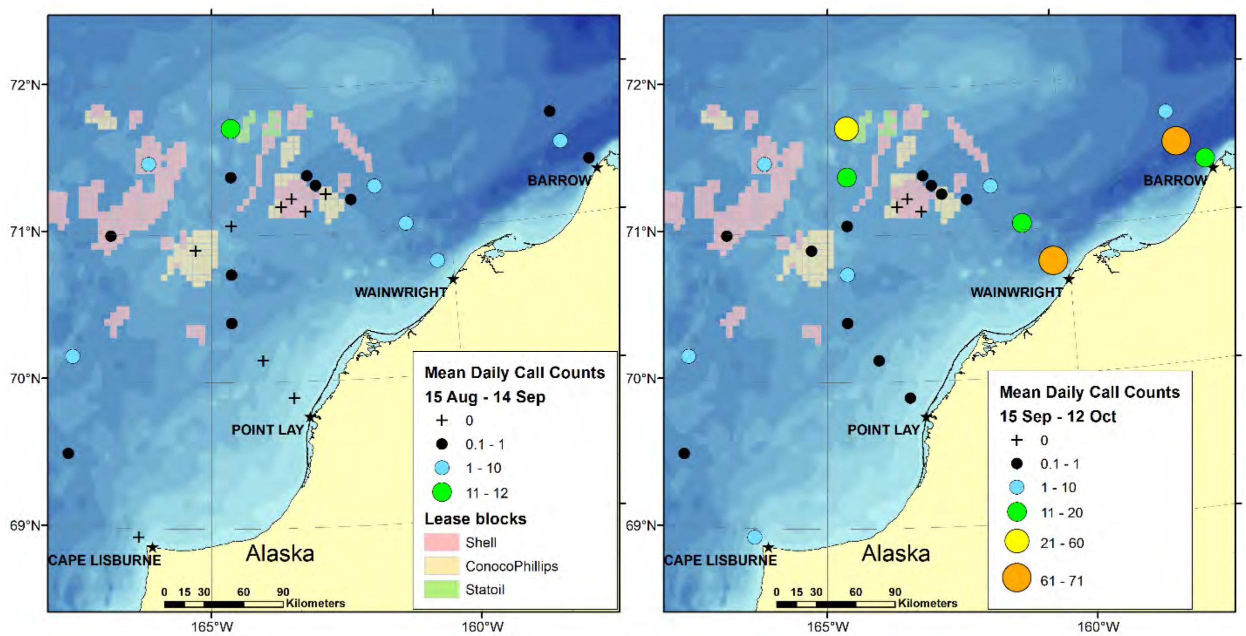

Figure C-7. Mean daily bearded seal call counts in the northeastern Chukchi Sea from (Left) 15 Aug to 14 Sep 2015 and (Right) from 15 Sep to 12 Oct at all operational summer recording stations in the northeastern Chukchi Sea.

Table C-9. Summer 2015 gray whale call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percent of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections are omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B5	13 Aug	14 Aug	28 Sep	7 Oct	9	16.1
B15	13 Aug	17 Sep	3 Oct	7 Oct	2	3.6
B30	13 Aug	22 Aug	6 Sep	8 Oct	2	3.5
BG03	25 Jul	16 Aug	23 Aug	2 Oct	2	2.9
CL50	15 Aug	22 Aug	22 Aug	11 Oct	1	1.7
CLN40	15 Aug	25 Aug	25 Aug	9 Oct	1	1.8
HSW1	16 Aug	19 Aug	19 Aug	2 Oct	1	2.1
KL01	14 Aug	22 Aug	22 Aug	4 Oct	1	1.9
PL30	11 Aug	12 Aug	13 Sep	9 Oct	5	8.3
PL50	11 Aug	12 Aug	19 Sep	9 Oct	2	3.3
PLN60	14 Aug	2 Sep	2 Sep	3 Oct	1	2.0
W10	11 Aug	12 Aug	21 Sep	6 Oct	9	15.8
W30	11 Aug	13 Aug	28 Sep	6 Oct	5	8.8
W50	14 Aug	1 Sep	23 Sep	5 Oct	9	16.4

Table C-10. Summer 2015 killer whale call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percent of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections are omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B5	13 Aug	23 Sep	28 Sep	7 Oct	2	3.6
B15	13 Aug	28 Sep	28 Sep	7 Oct	1	1.8
B30	13 Aug	28 Sep	28 Sep	8 Oct	1	1.8
BG03	25 Jul	22 Sep	23 Sep	2 Oct	2	2.9
CL5	10 Aug	15 Aug	16 Aug	11 Oct	2	3.2
CL50	15 Aug	4 Sep	4 Sep	11 Oct	1	1.7
CLN40	15 Aug	4 Sep	22 Sep	9 Oct	3	5.4
CLN90B	15 Aug	17 Sep	22 Sep	4 Oct	3	5.9
CLN120B	15 Aug	13 Sep	27 Sep	3 Oct	3	6.0
HSW1	16 Aug	22 Sep	22 Sep	2 Oct	1	2.1
HSW2	16 Aug	23 Sep	23 Sep	2 Oct	1	2.1
HSW3	16 Aug	23 Sep	23 Sep	2 Oct	1	2.1
HSW4	16 Aug	19 Aug	19 Aug	2 Oct	1	2.1
PL10	10 Aug	18 Sep	19 Sep	12 Oct	2	3.1
PL50	11 Aug	26 Sep	26 Sep	9 Oct	1	1.7
PLN60	14 Aug	27 Sep	27 Sep	3 Oct	1	2.0
PLN80	15 Aug	13 Sep	17 Sep	3 Oct	2	4.0
W10	11 Aug	31 Aug	1 Sep	6 Oct	2	3.5
W30	11 Aug	24 Aug	18 Sep	6 Oct	5	8.8
W50	14 Aug	16 Sep	22 Sep	5 Oct	4	7.3

Table C-11. Winter 2014–2015 ringed seal call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number of days on which a call was detected manually for each recording station in the northeastern Chukchi Sea. The recorders operated for 5 min every 30 min.

Station	Record start	First detection	Last detection	Record end	Detection days
CL5	17 Oct	12 Nov	30 May	10 Aug	112
PL10	9 Oct	29 Oct	28 Nov	29 Nov	14
PL50	9 Oct	16 Nov	21 Jun	11 Aug	106
PLN40	13 Oct	16 Nov	30 Nov	9 Dec	2
W10	15 Oct	27 Jan	11 Jun	11 Aug	56
W50	16 Oct	8 Nov	27 Jan	27 Jan	31
WN40	12 Oct	11 Dec	8 Jun	30 Aug	30

Table C-12. Summer 2015 ringed seal call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percent of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections are omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B5	13 Aug	17 Sep	17 Sep	7 Oct	1	1.8
B15	13 Aug	17 Sep	4 Oct	7 Oct	11	19.6
B30	13 Aug	23 Aug	4 Oct	8 Oct	16	28.1
CL5	10 Aug	15 Aug	15 Aug	11 Oct	1	1.59
CLN40	15 Aug	24 Aug	30 Sep	9 Oct	2	3.57
PLN60	14 Aug	8 Sep	8 Sep	3 Oct	1	1.96
W10	11 Aug	19 Sep	20 Sep	6 Oct	2	3.51

Appendix D. Estimating the Detection Range of Bowhead Moans

This appendix describes how the detection range of bowhead moans was calculated for each recorder of the summer 2015 Program.

D.1. Methods

The received sound level (*RL*) of a bowhead moan at a recorder is defined by the following equation (Urick 1983):

$$RL = SL - TL \quad (1)$$

where *SL* is the source level of the bowhead moan, and *TL* is the transmission loss between the whale and the hydrophone. The detection range of a bowhead moan was assumed to be the distance from the recorder for which the received level of the bowhead call equaled or exceeded the noise level at the recorder (*NL*):

$$NL = RL. \quad (2)$$

Cummings and Holliday (1987) and Clark et al. (1986) estimated that source levels of simple moans range from ~128 to 178 dB re 1 µPa at 1 m. MacDonnell et al. (2011) estimated that bowhead moans recorded near the Burger lease area had source levels of 144.3 ± 4.6 dB re 1 µPa at 1 m (mean ± standard deviation), with minimum and maximum levels of 129.7 and 164.4 dB respectively (Figure D-1). These latter values were used for estimating the bowhead detection range at each recorder Equation 1.

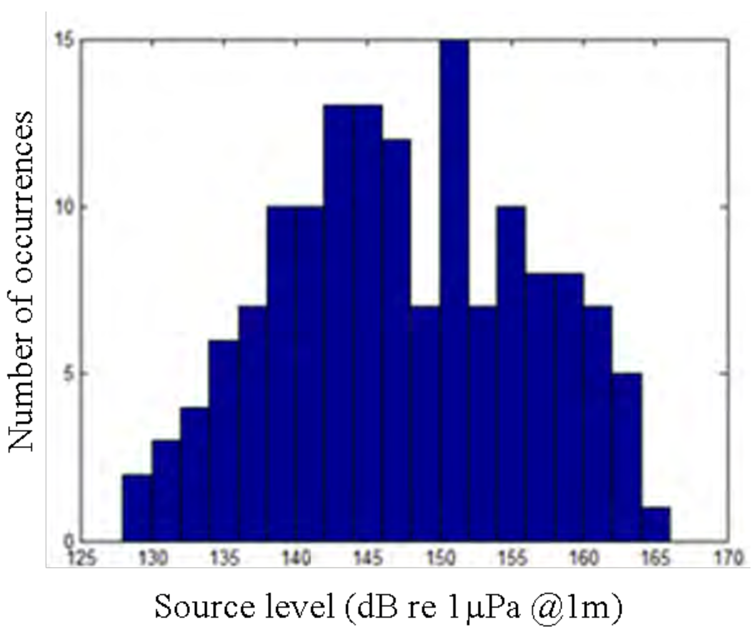

Figure D-1. Distribution of source levels reported by MacDonnell and Martin (2011).

Transmission loss values used for estimating the bowhead detection range came from a previous study by MacDonnell and Martin (2011) at the Burger lease area. In that study, transmission loss was calculated between 89 and 447 Hz using JASCO's Marine Operations Noise Model (Hannay and Racca 2005, Austin 2012). This frequency range comes from using the seven 1/3-octave bands centered between 100 and 400 Hz. Figure D-2 shows a transmission loss map calculated by (MacDonnell and Martin 2011) at BG01 (summer 2009).

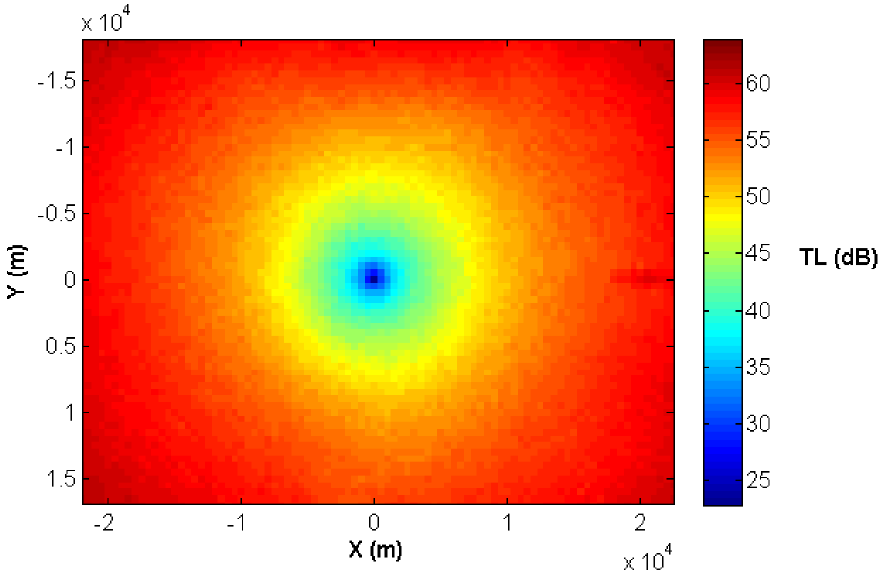

Figure D-2. Map of the transmission loss values calculated by MacDonnell and Martin (2011) at station BG01 (summer 2009). x is east-west distance in meters. y is north-south distance in meters.

The water depth in the eastern Chukchi Sea is nearly constant. Consequently, the transmission loss is nearly the same for all azimuths (Figure D-2). To simplify the calculation of the detection range, the transmission loss values from MacDonnell and Martin (2011) were represented by one equation:

$$TL(R) = A \log_{10}(R) + \alpha R \tag{3}$$

where, R is the distance from hydrophone to whale, A is the spreading coefficient and α is the attenuation coefficient (Urick 1983). The coefficients A and α were defined by fitting (in the least square sense) Equation (3) to the average transmission loss taken in four different azimuths from the recorder (i.e., 0°, 90°, 180°, and 270°). Figure D-3(left) shows the transmission loss curve from MacDonnell et al. (2011) at the location BG01 in four different azimuths. Figure D-3 (right) shows the average transmission loss curve with its simplified transmission loss function.

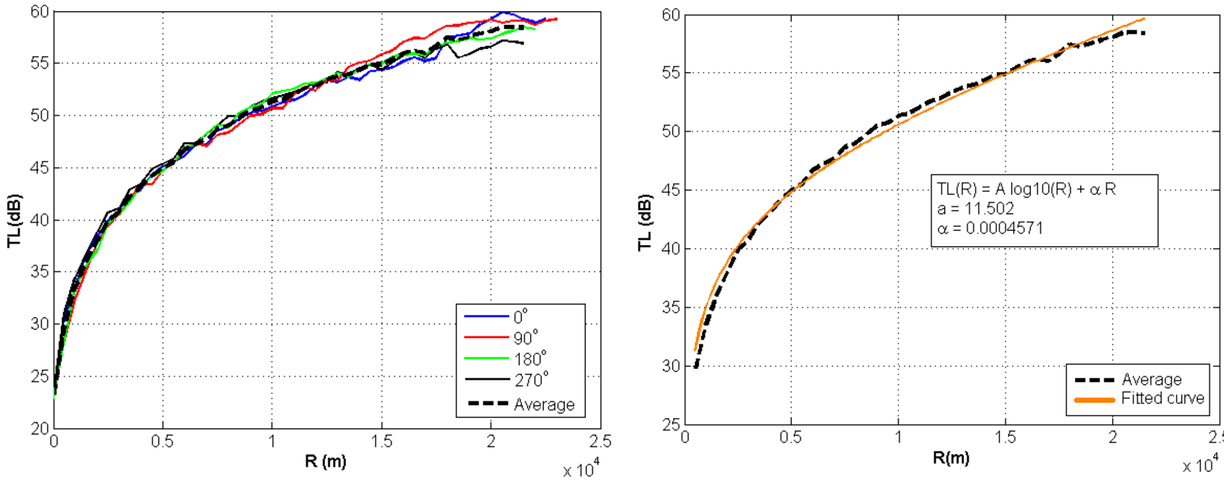

Figure D-3. Transmission loss modeled by MacDonnell et al. (2011) at location BG01. (Left) Transmission loss curves in four different azimuths. (Right) Average transmission loss and its simplified transmission loss function.

Coefficients A and α were calculated for each location modeled by MacDonnell et al. (2011) and then averaged to obtain a single set of coefficients for the whole area. Final coefficients used for the detection range analysis were $A = 11.29$ and $\alpha = 0.00057$.

Noise levels used for estimating the bowhead detection range were calculated for every minute of recording by summing the 1/3-octave band levels between 89 and 447 Hz.

The detection range was calculated at each recorder and for each minute of recording. The probability of detecting a bowhead moan at a given range was the number of 1 min recordings with a detection range equal to or greater than the given range divided by the number of 1 min recordings. Detection ranges were calculated independently for each recorder.

A Monte Carlo method accounted for the measured variability in source levels. Detection ranges were re-calculated 50 times by randomly choosing 50 normally distributed source level values, with the means and standard deviations defined by MacDonnell et al. (2011; Figure D-3), Consequently, a distribution of probability is associated with each range.

D.2. Results

Figure D-4 through Figure D-30 show the detection probability of bowhead moans at each recorder.

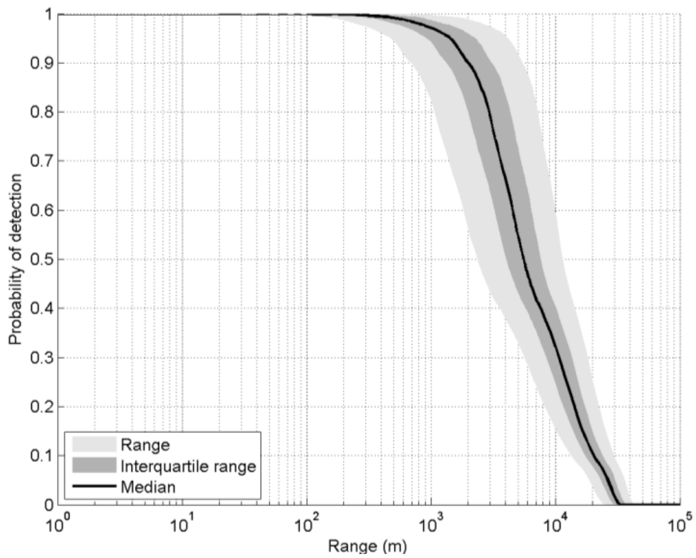

Figure D-4. Detection probability of bowhead moans at Station B5. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

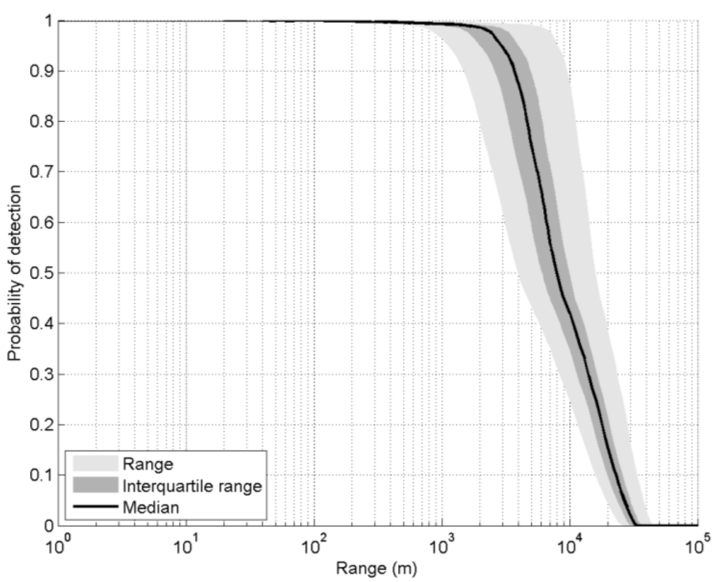

Figure D-5. Detection probability of bowhead moans at Station B15. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

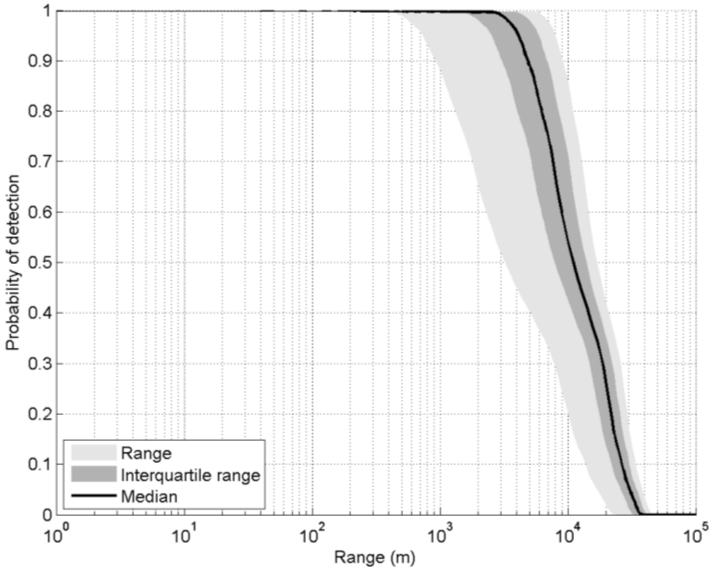

Figure D-6. Detection probability of bowhead moans at Station B30. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

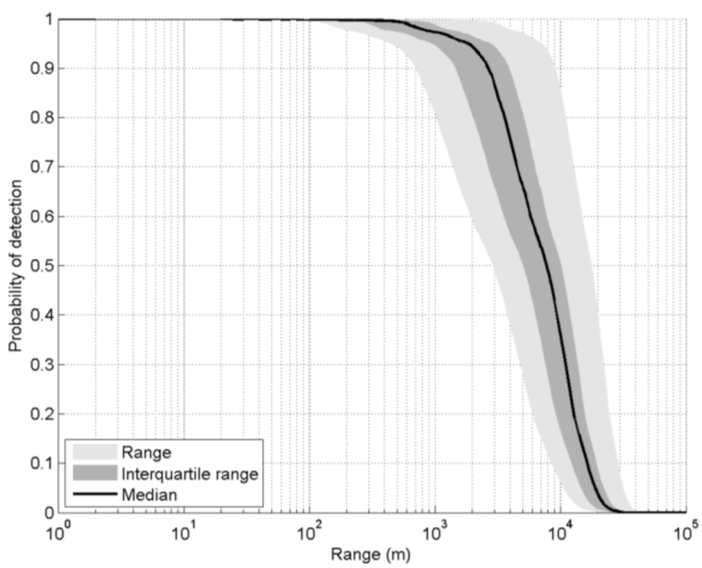

Figure D-7. Detection probability of bowhead moans at Station W10. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

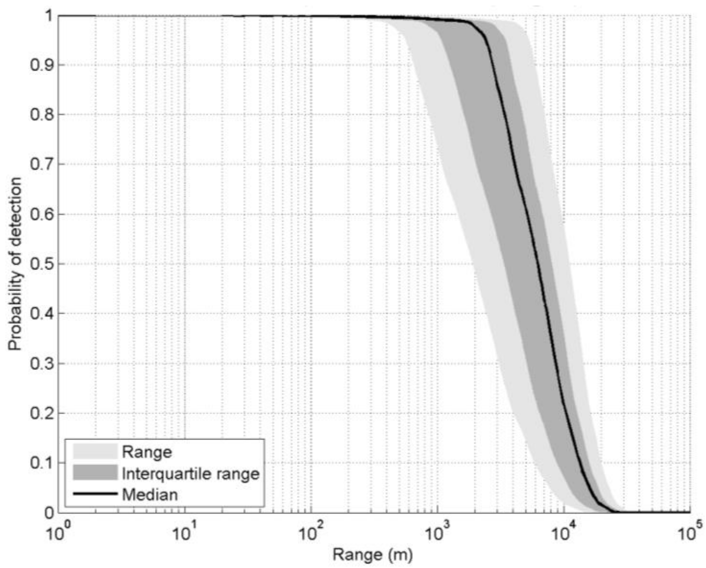

Figure D-8. Detection probability of bowhead moans at Station W30. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

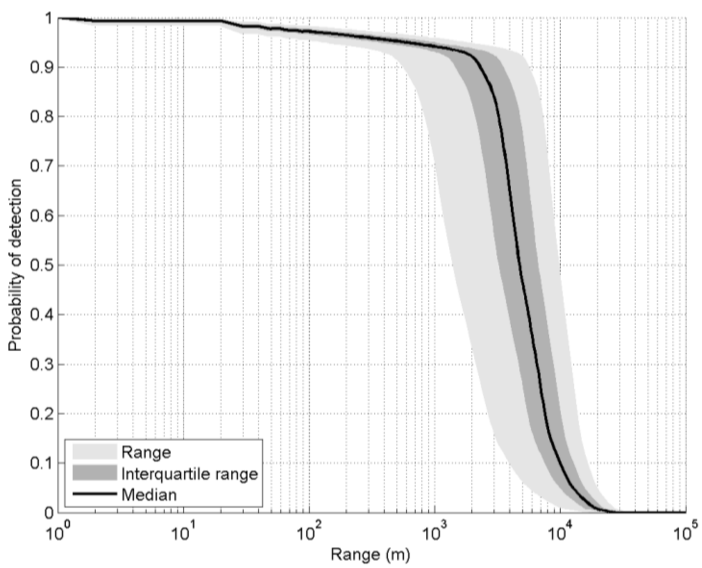

Figure D-9. Detection probability of bowhead moans at Station W50. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

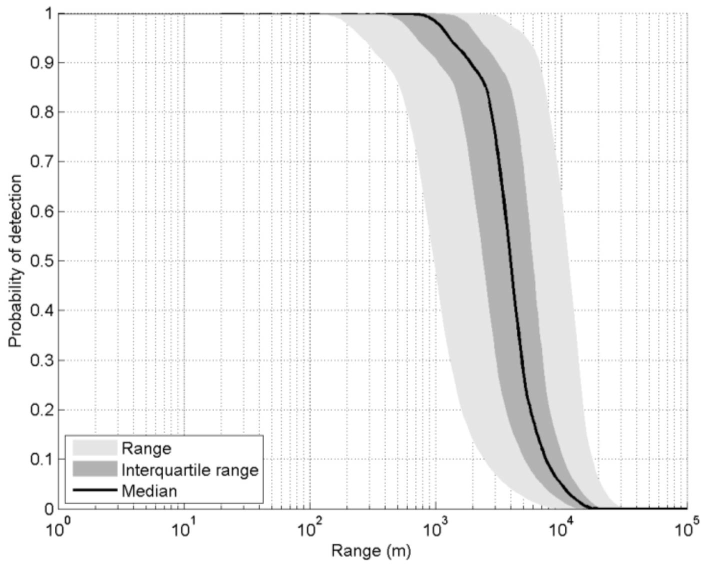

Figure D-10. Detection probability of bowhead moans at Station HSW1. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

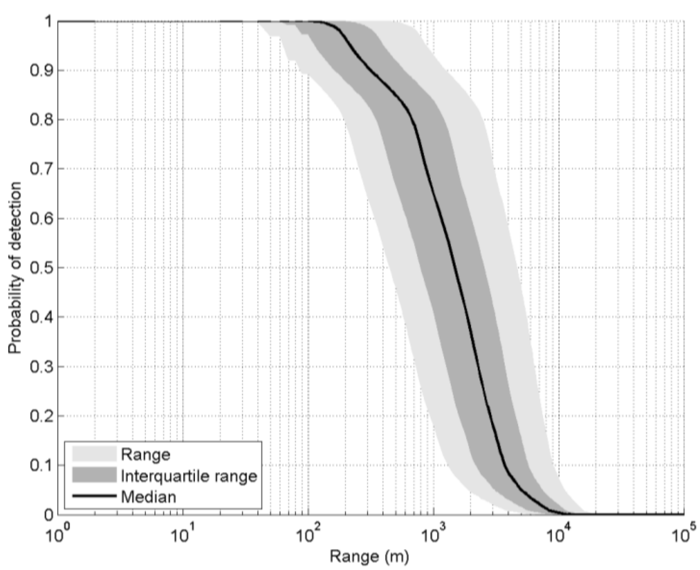

Figure D-11. Detection probability of bowhead moans at Station HSW2. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

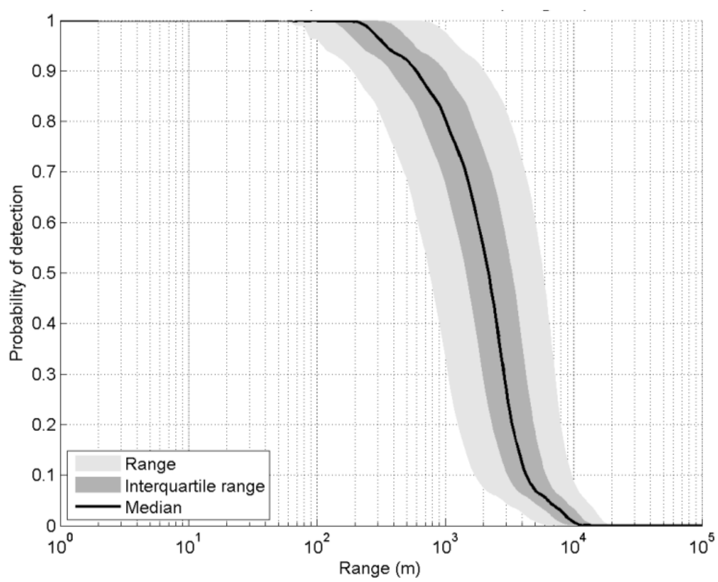

Figure D-12. Detection probability of bowhead moans at Station HSW3. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

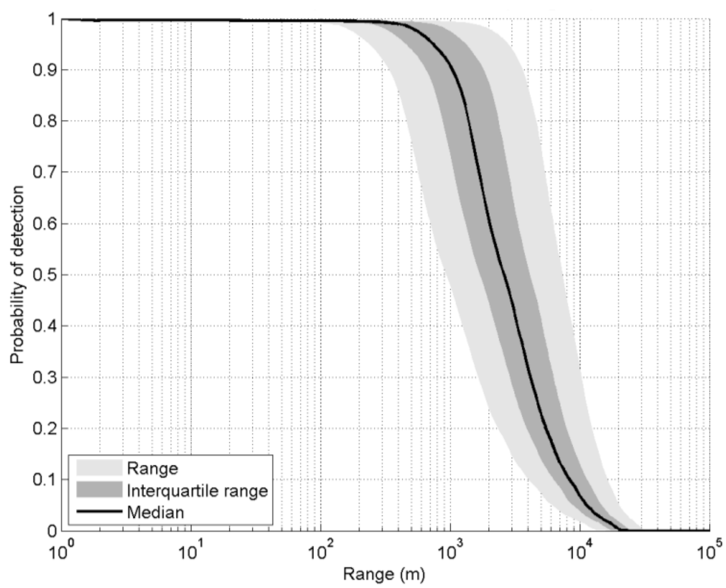

Figure D-13. Detection probability of bowhead moans at Station PL10. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

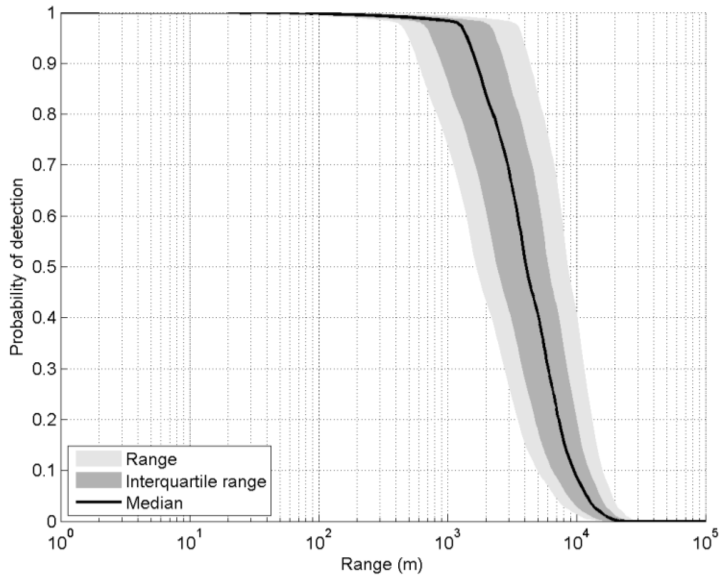

Figure D-14. Detection probability of bowhead moans at Station PL30. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

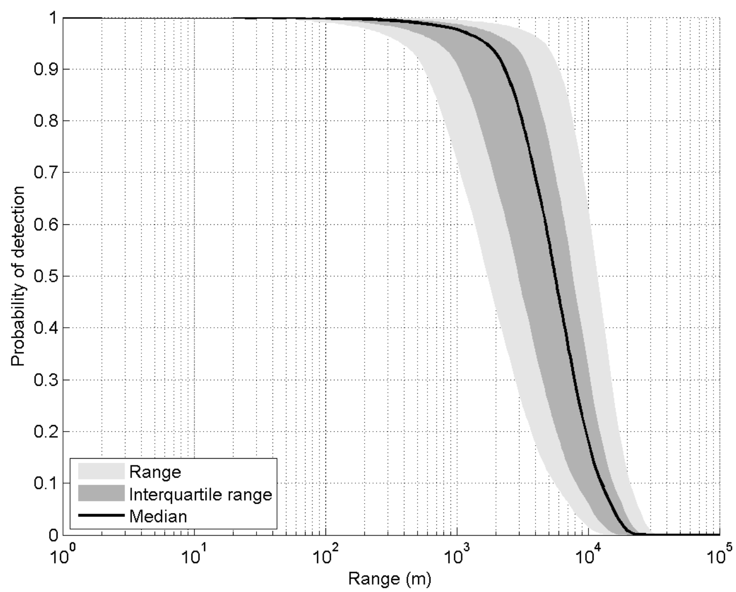

Figure D-15. Detection probability of bowhead moans at Station PL50. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

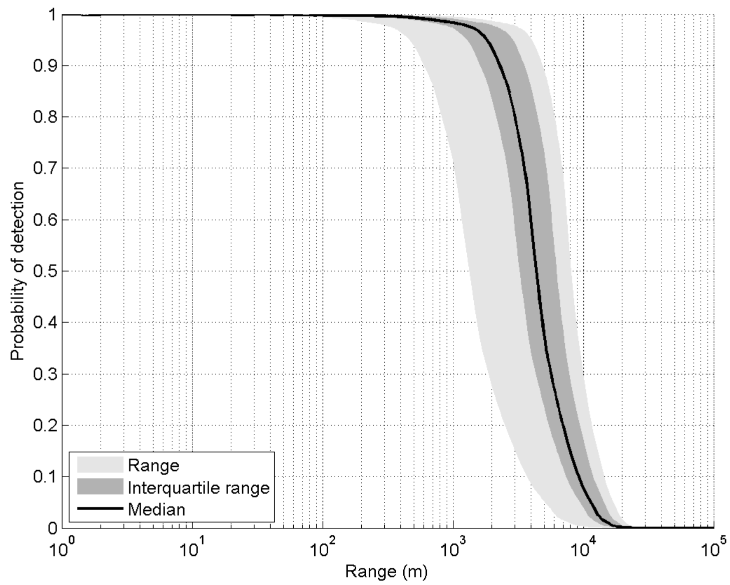

Figure D-16. Detection probability of bowhead moans at Station PLN20. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

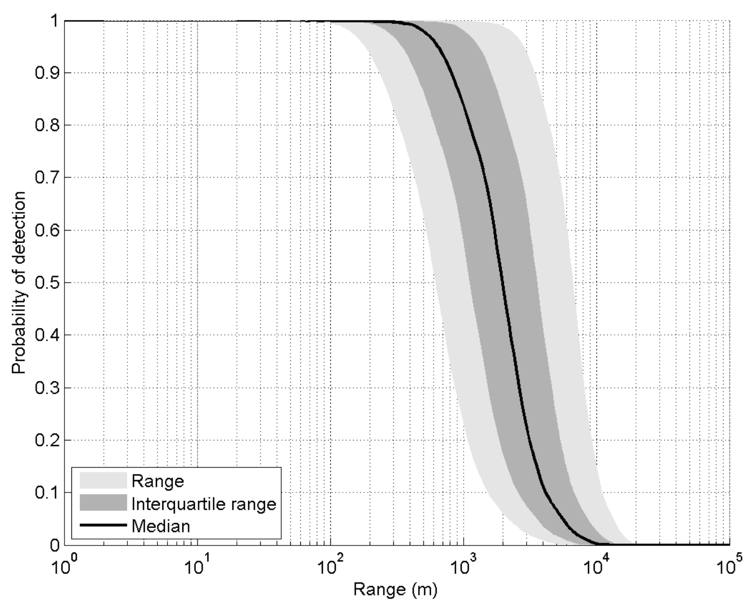

Figure D-17. Detection probability of bowhead moans at Station PLN40. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

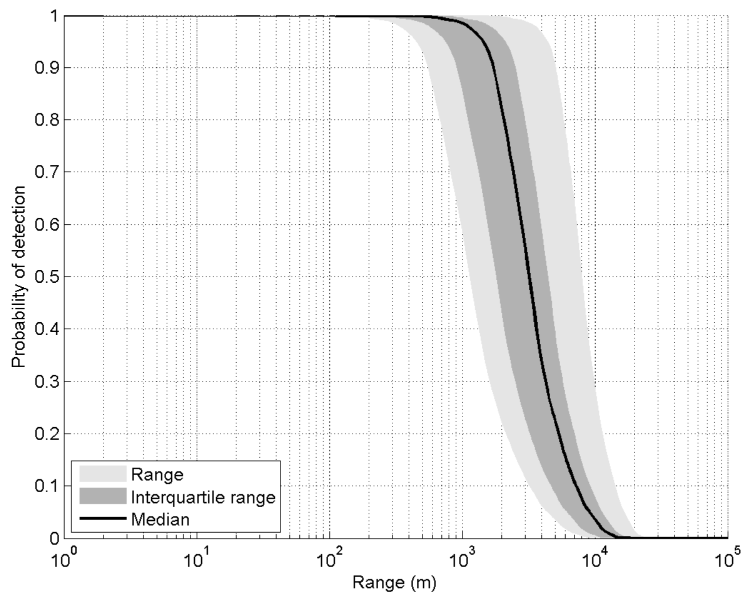

Figure D-18. Detection probability of bowhead moans at Station PLN60. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

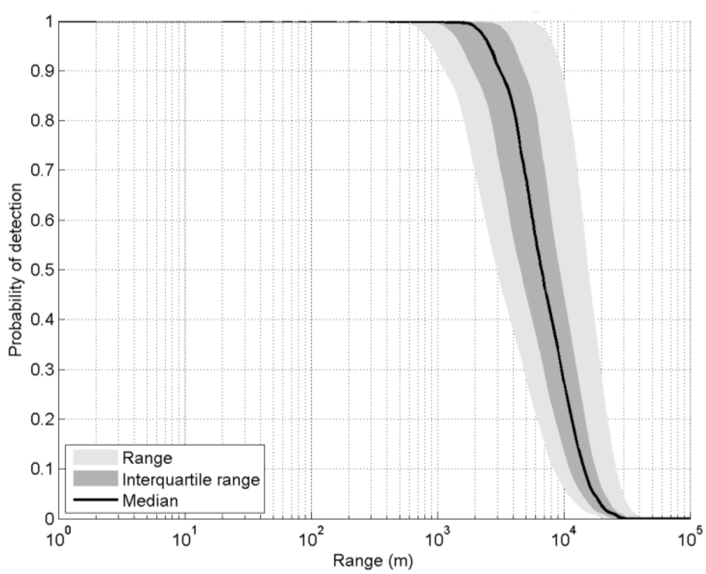

Figure D-19. Detection probability of bowhead moans at Station PLN80. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

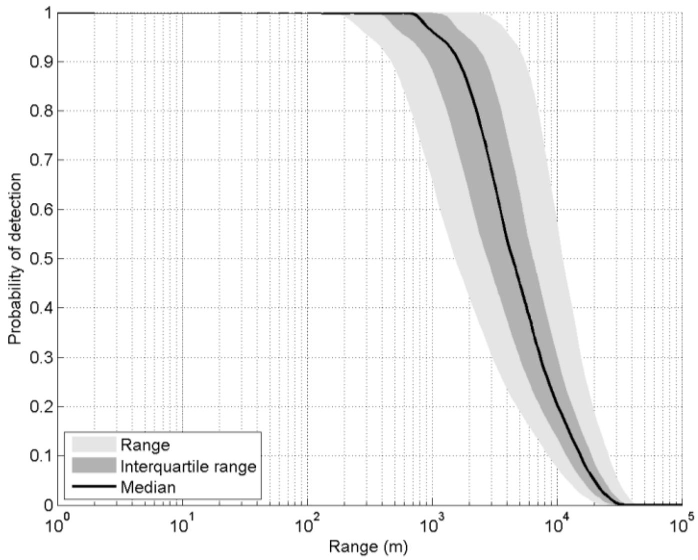

Figure D-20. Detection probability of bowhead moans at Station CL5. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

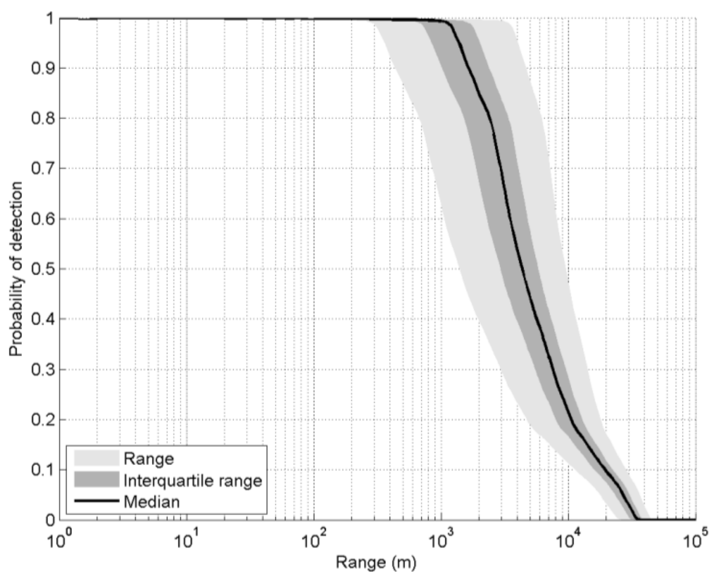

Figure D-21. Detection probability of bowhead moans at Station CL50. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

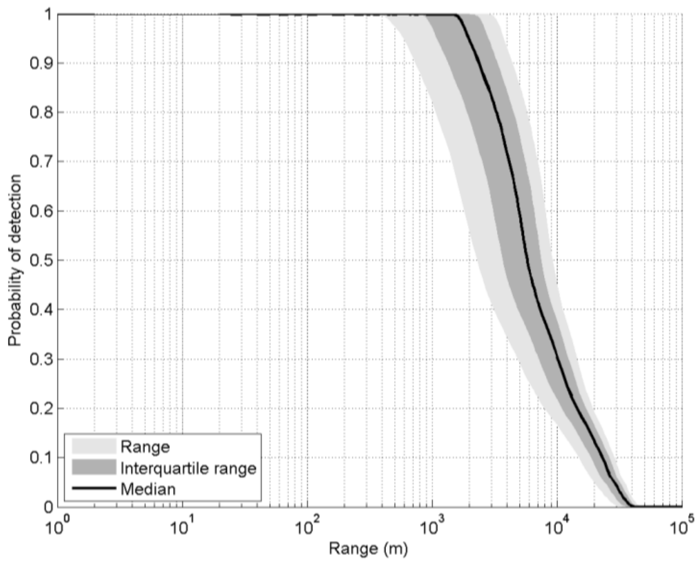

Figure D-22. Detection probability of bowhead moans at Station CLN40. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

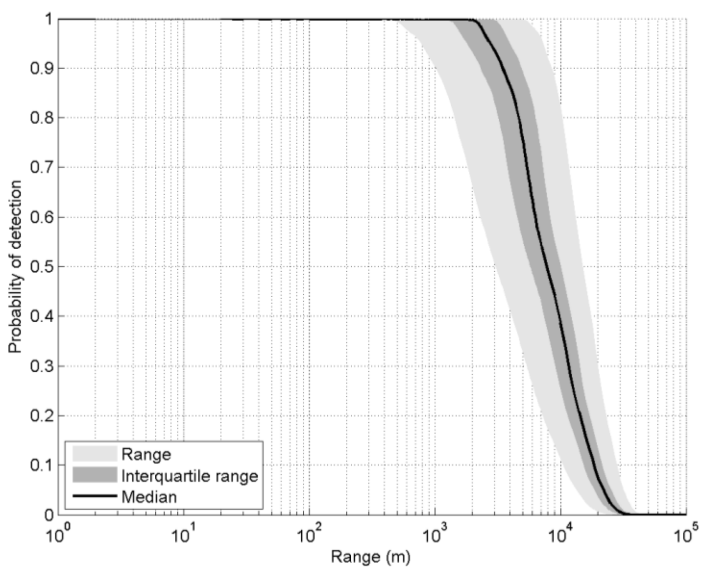

Figure D-23. Detection probability of bowhead moans at Station CLN90B. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

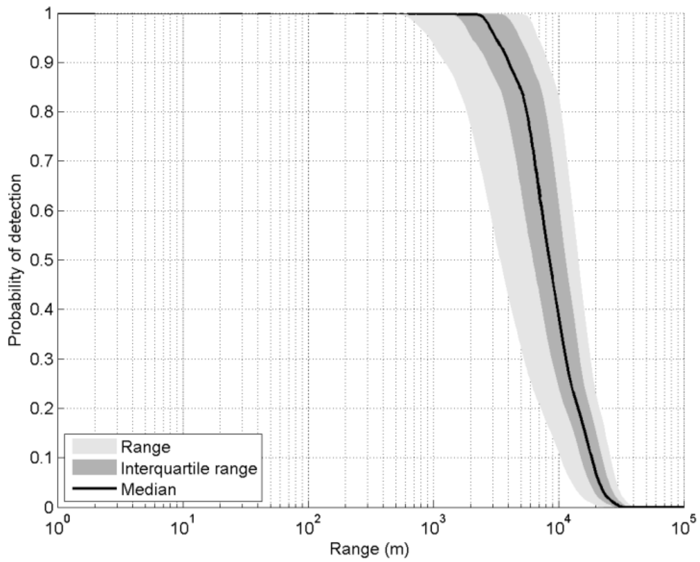

Figure D-24. Detection probability of bowhead moans at Station CLN120B. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

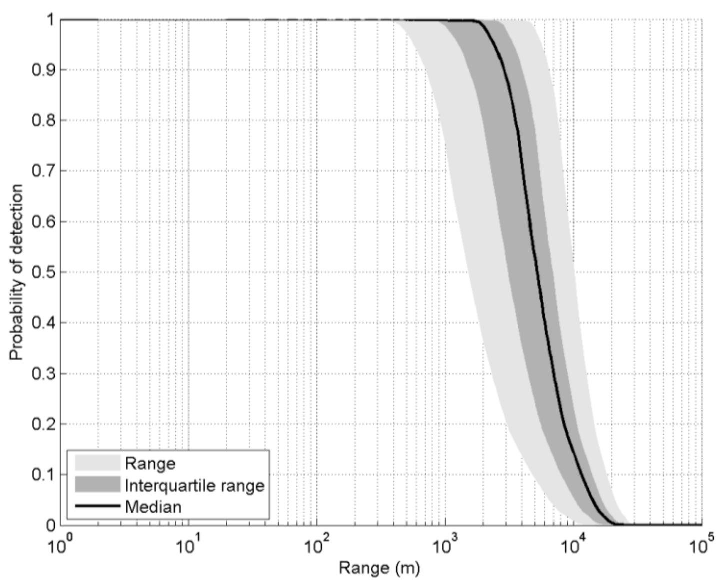

Figure D-25. Detection probability of bowhead moans at Station KL01. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

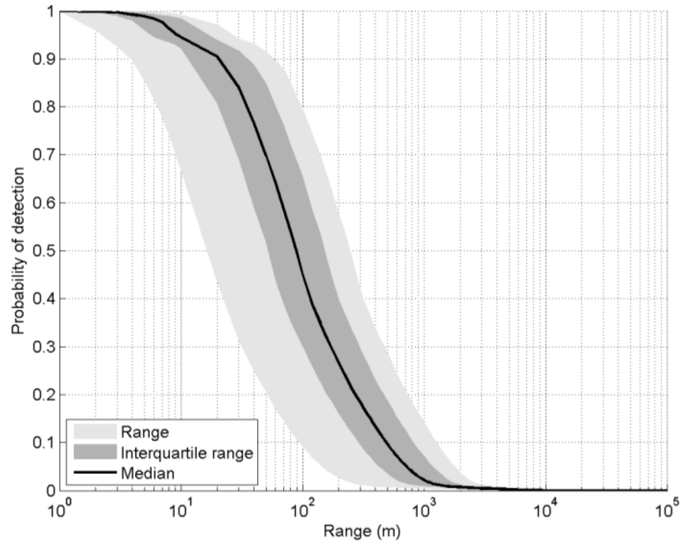

Figure D-26. Detection probability of bowhead moans at Station BG01. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

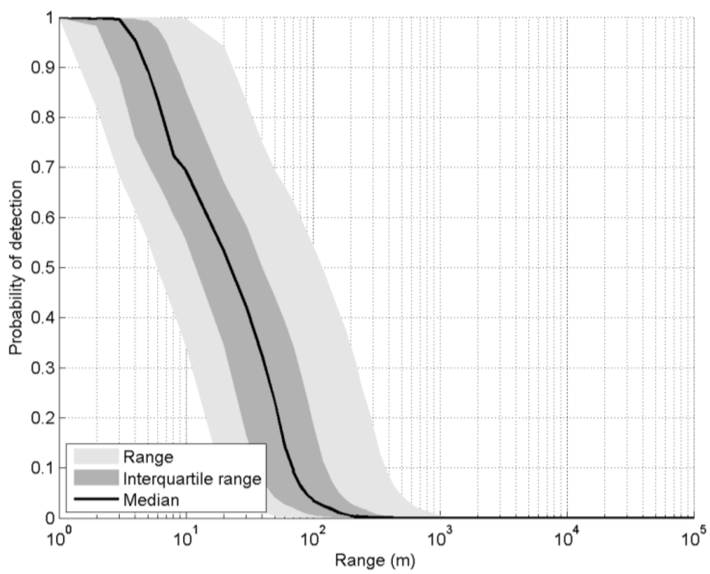

Figure D-27. Detection probability of bowhead moans at Station BG02. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

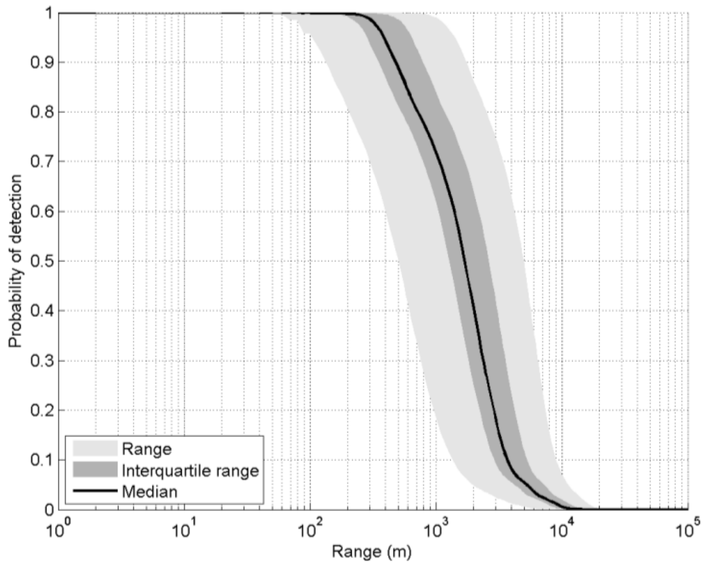

Figure D-28. Detection probability of bowhead moans at Station BG03. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

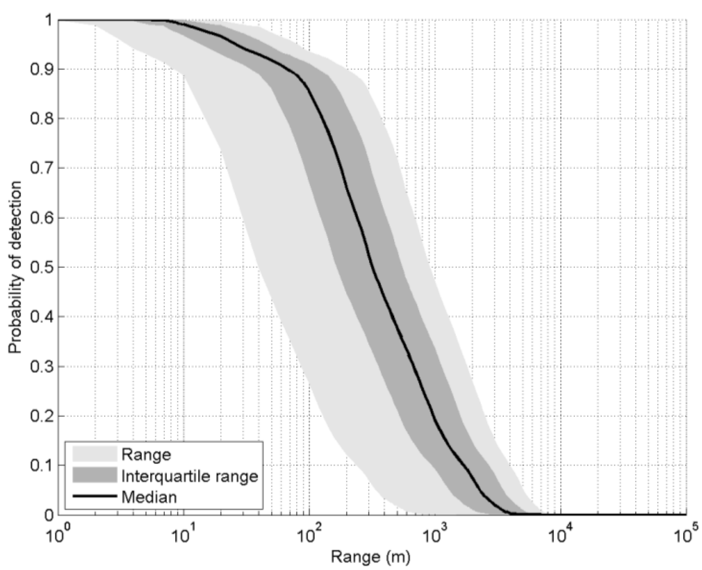

Figure D-29. Detection probability of bowhead moans at Station BG_J16. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

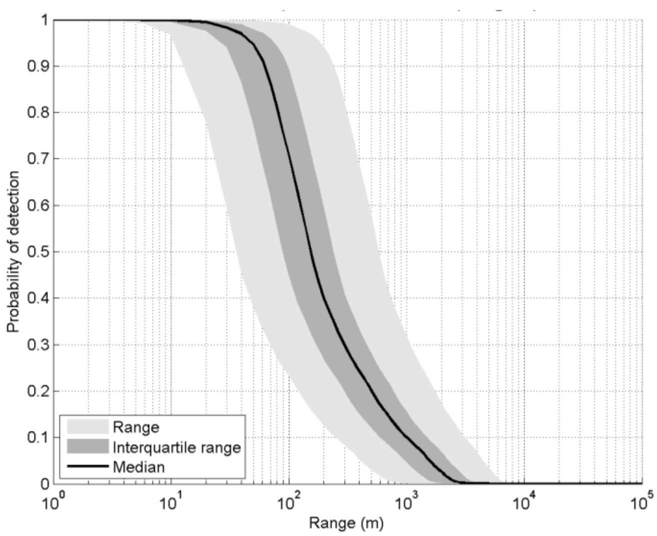

Figure D-30. Detection probability of bowhead moans at Station BG_V16. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from the 5th to the 95th percentile), and the dark gray areas the probability interquartile range (from the 25th to the 75th percentile).

D.3. Discussion

The maximum detection ranges calculated in this study are consistent with maximum detection ranges reported in the literature. Cummings and Holliday (1985) and Clark et al. (1986) detected bowhead moans off Barrow up to 20 km from a hydrophone, although most of the bowhead moans they localized were less than 10 km away. Figure D-4 and Figure D-5 show similar results with a maximum detection range of approximately 20 km near Barrow.

Figure D-31 shows the median detection probability range at all the Burger stations. The median detection range at BGV16 is shorter than at other stations.

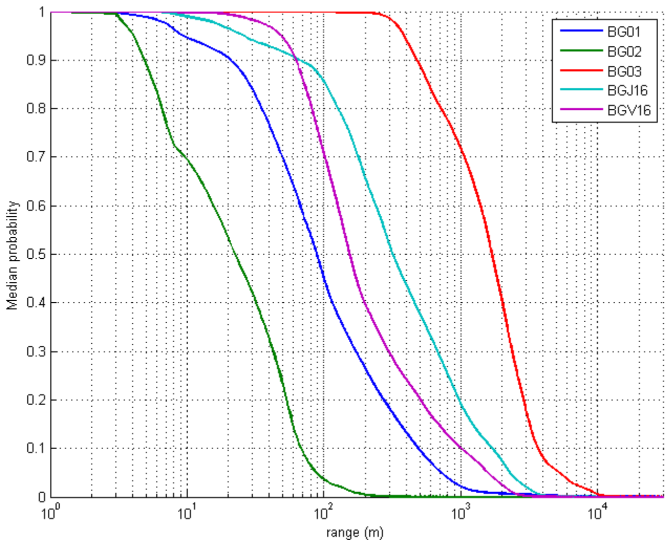

Figure D-31. Comparison of the 50th percentile probability of detection range for bowhead moans at the Burger stations.

Detection range estimates (median probability) at stations PLN20, PLN40, and PLN60 were shorter in summer 2015 than previous years (Figure D-32).

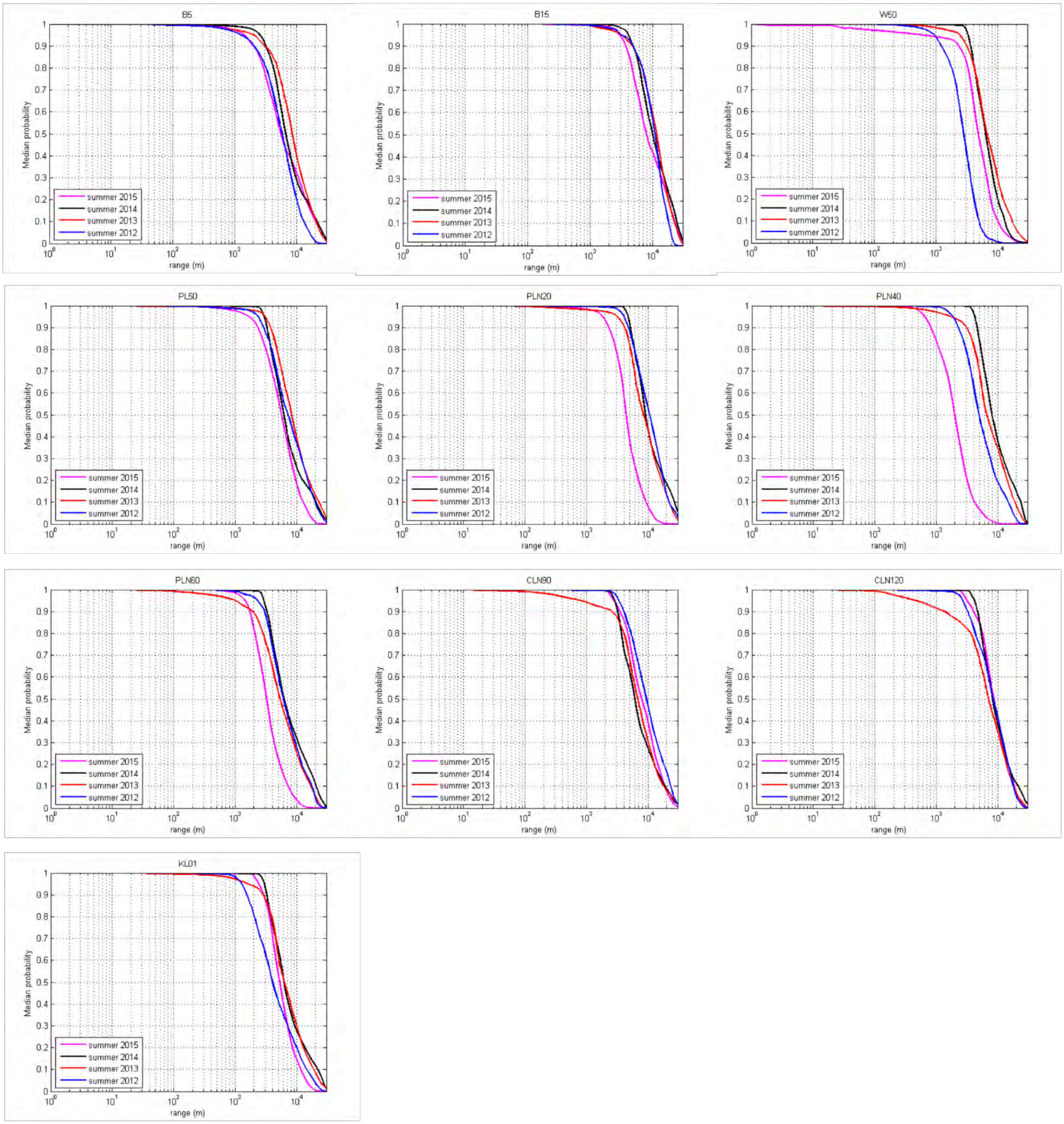

Figure D-32. Comparison of 50th percentile probability of detection range for bowhead moans between summer 2012 through 2015 at several stations.

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